TRANSACTIONS

of the

American Foundrymen's Association

Proceedings of the

Thirty-fifth Annual Meeting

Chicago, Ill.

May 4 to 7, 1931

VOLUME XXXIX

EDITED BY ROBERT E. KENNEDY

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Officers

of the

American Foundrymen's Association

INCORPORATED

President

E. H. BALLARD
General Electric Co., West Lynn, Mass.

Vice-President

T. S. HAMMOND
Whiting Corporation, Harvey, Ill.

Executive Secretary-Treasurer

C. E. HOYT
222 W. Adams St., Chicago

Technical Secretary

R. E. KENNEDY
222 W. Adams St., Chicago

MEMBERS OF THE BOARD OF DIRECTORS

(In addition to the President, Vice-Pres. and Executive Secy.)

C. S. ANDERSON,
Belle City Malleable Iron Co.,
Racine, Wis.

D. M. AVEY,
The Foundry,
Cleveland.

H. R. CULLING,
Carondelet Foundry Co.,
St. Louis.

FRED ERB,
Eaton-Erb Foundry Co.,
Vassar, Mich.

HAROLD S. FALK,
Falk Corporation,
Milwaukee.

S. T. JOHNSTON,
S. Obermayer Co.,
Chicago.

FRANK J. LANAHAN,
Fort Pitt Malleable Iron Co.,
Pittsburgh.

ARNOLD LENZ,
Chevrolet Motor Co.,
Saginaw, Mich.

R. M. MAULL,
Tabor Mfg. Co.,
Philadelphia.

W. D. MOORE,
American Cast Iron Pipe Co.,
Birmingham, Ala.

N. K. B. PATCH,
Lumen Bearing Co.,
Buffalo.

D. M. SCOTT,
Buffalo Electric Furnace Co.,
Buffalo.

A. G. STORIE,
Fittings, Limited,
Oshawa, Ont., Canada.

FRED L. WOLF,
Ohio Brass Co.,
Mansfield, Ohio.

DELOS H. WRAY,
Henry Wray & Son, Inc.,
Rochester, N. Y.

Reports of Official Acts of the Board of Directors and of Committees Thereof

In this report are shown minutes of the following meetings of the Board of Directors held during 1931:

May 7—Meeting of the Directors held on the closing day of the annual Convention.

July 9—Final meeting of the old Board, followed by a meeting of the 1931-32 Board.

November 19—Meeting of the Executive Committee.

Following the minutes of these meetings are reported the meeting of the Nominating Committee held January 15, 1932, and the meeting of the Board of Awards November 19, 1931.

These constitute a report of all official meetings of the Association held in 1931-32, except the annual Business Meeting of the Association held during the Chicago Convention and reported in the *Transaction and Bulletin* for May, 1931.

Membership

The report of the Executive Secretary submitted at the annual Board meeting on July 9, 1931, showed the book membership on January 1, 1931, as 2477

New members elected to date of June 30	81
Resignations	110
Delinquents dropped	76
Removed by death	4
Total loss	190
Net loss January 1 to June 30	109
Book membership June 30, 1931	2368

Finances

The Treasurer, in submitting his financial report at the annual Board meeting on July 9, stated that the Finance Committee had authorized the inclusion of the six-month period January 1 to June 30, 1931 in the official audit of the books to be made at the end of the fiscal year closing

June 30, 1932. The unaudited report, which the Finance Committee reported having examined and found satisfactory, gave the net worth of the Association as of June 30, 1931, as $69,001.38, made up as follows:

Cash in bank	$13,512.34
Accounts receivable	1,054.75
Furniture, fixtures and supplies	2,260.60
Special research funds	2,248.13
Reserve fund (securities at par)	49,925.56

(The above figures do not include award fund securities, the income only from which is available for certain specific purposes.)

NOTE: While the record of proceedings and official acts for the year 1932 does not appear in these TRANSACTIONS, it should be recorded here that the Finance Committee, acting upon the recommendations of the Executive Secretary-Treasurer submitted at the Board meetings held May 7 and July 9, and by authorization given them at the meeting of the Executive Committee on November 19, made substantial salary reductions, and that following cancellation late in February of all exhibit plans for 1932, authorized still further reductions.

In submitting a report to the Directors on salary readjustments the Executive Secretary stated that the reductions ranged from 30 per cent to 50 per cent. Coupled with this was the announcement that other economies had been effected, including a reduction in rent and saving in cost of publications by putting the monthly *Transactions* on a bi-monthly basis.

It was estimated that the cancellation of exhibits, which finance approximately 40 per cent of Association activities, would result in an operating loss of approximately $22,000 for the fiscal year ended June 30, 1932.

Minutes of Convention Meeting 1930-31 Board of Directors

AMERICAN FOUNDRYMEN'S ASSOCIATION
HOTEL STEVENS, CHICAGO, MAY 7, 1931

(Following the Annual Alumni Dinner)

President N. K. B. Patch presiding.

Roll Call

Officers and Directors present: President N. K. B. Patch, Vice President E. H. Ballard; Directors C. E. Hoyt, B. H. Johnson, P. J. Krentz, S. W. Utley, F. L. Wolf, Arnold Lenz, D. H. Wray, C. S. An-

derson, Fred Erb and R. M. Maull. Absent: H. S. Falk, S. T. Johnston, Frank J. Lanahan, H. R. Culling and D. M. Scott.

Directors-elect present: D. M. Avey, T. S. Hammond, W. D. Moore and A. G. Storie. Others present: B. D. Fuller, V. E. Minich, H. S. Simpson, S. C. Vessy and R. E. Kennedy.

Silent Tribute to Memory of Past Officers

Immediately the roll call had been taken, President Patch requested all present to stand with him in silent tribute to the memory of Dr. Richard Moldenke, former Secretary-Treasurer of the Association, whose death occurred Nov. 17, 1930; Alfred E. Howell, former President and Director, whose death occurred Jan. 25, 1931; and R. J. Doty, who died Feb. 24, 1931, shortly after being advised of his nomination as a Director of the American Foundrymen's Association.

Following this tribute the Secretary announced that in accordance with action of the Board of Directors at a special meeting held in New York on November 19, resolutions had been prepared on the death of Dr. Moldenke by a committee consisting of past-presidents Alfred E. Howell and G. H. Clamer. The Secretary stated that resolutions written by Alfred Howell had been delivered by him to the Secretary just five days prior to his death. He then passed around an engrossed and bound copy of these resolutions, which had been prepared for the widow of Dr. Moldenke.

The Secretary also announced that a committee consisting of past presidents R. A. Bull, G. H. Clamer and S. T. Johnston had been appointed by President Patch to prepare resolutions on the death of Alfred Howell. These resolutions, which were read at the annual meeting of the Association in the afternoon, were again read that they might appear as a matter of record in the minutes of this meeting:

> "One of the most satisfying emotions man can have is prompted by the realization of outstanding service given himself by another. When there are exemplified in the faithful servant, broad culture, discerning judgment, unassailable character and rare good fellowship, it becomes a privilege to record appreciation.
>
> "A relationship of the kind indicated existed between the American Foundrymen's Association and Alfred E. Howell, deceased Past President. He was a valued member of the Association for twenty-three years, and of the Board of Directors for seventeen years. He filled the offices, progressively, of Vice-President and President. He was eventually elected to Honorary Membership. Such unusual service demonstrated Alfred E. Howell's genius for stimulating the spirit of cooperation, the most important principle of those essential for the success of the Association.
>
> "Alfred Howell had a keen appreciation, inborn and cultivated, of all that is beautiful in nature and in art. He sensed, in a degree unusual for one in his occupation, those

finer elements to be found amid the smoke and grime of the foundry, which glorify honest toil and constructive labor.

"*Be It Resolved*, because of the circumstances mentioned, that the members of the American Foundrymen's Association, in convention assembled, declare their lasting affection for Alfred Howell, their sincere gratitude for the talents given by him freely for the best interests of the Association, and their personal sorrow caused by the death of their old friend; and

"*Be It Further Resolved*, that this tribute be spread on the official record of the *Transactions* of the American Foundrymen's Association; also that the Association convey to Mrs. Howell, now bereft of her loving companion, an expression of our deep sympathy, with suitable notification regarding these resolutions."

Authorization of Resolutions on Death of R. J. Doty

The President was authorized to appoint a committee to prepare resolutions on the death of R. J. Doty, to be presented at the next Board meeting.

Address by President Patch

President Patch then addressed those present, referring to the annual Alumni meetings as a getting-together of those who had given of their time, energy and thought without stint to the interests of the Association, with those who were newer at the game, to consider together the purposes for which the Association was organized. President Patch stated that it was his earnest desire to point out how the Association could be of maximum service, not only to the foundry industry but to the nation as a whole. In closing he said:

"Let us, therefore, in all policies of the Board bear in mind that we have a sacred trust to preserve, this friendly cooperative spirit, and one way to preserve it is to cultivate our own back yard to that point where it is superlatively inviting to members and is not encroaching upon another's field, so that there is no development of inter-association ill will."

Report of Vice President as Chairman of Correlations Committee

Mr. Ballard reported that an interesting meeting of the Correlations Committee had been held during the convention, and he reviewed briefly the activities of each group as they had been presented by the various group chairmen. He invited discussion of a question on which there had been some difference of opinion, namely, the proper designation for these Association groups, whether they should be referred to as "Divisions" or "Sections" of the A. F. A. Following discussion, it was moved that the question of proper designation be referred to the Executive Committee for decision.

Report of Committee on International Relations

D. M. Avey, Chairman of the Committee on International Relations, reported that a meeting of the committee had been held during Convention Week and that much of the time had been given over to discussion of annual exchange papers between the A. F. A. and European foundry associations; that the committee had authorized him to conduct negotiations with a view to bringing about a more satisfactory arrangement and one that would insure a better quality of exchange papers.

Research Appropriations

The Secretary reported that at a special conference of members of the Research Appropriations Committee held the afternoon of May 7, attended by members of the Nonferrous Division, it was agreed to extend the time of employment of E. J. Ash, Research Associate at the U. S. Bureau of Standards, to date of September 1st, the cost of his services to be charged against the authorized appropriation for research on test bars and liquid shrinkage on high shrinkage alloys for nonferrous castings. In authorizing this extension of time, it was with the understanding that funds for drefraying the cost of any further research in this field by Mr. Ash would be provided through funds raised from the nonferrous casting industry.

Change in Fiscal Year

At a special meeting of the Board of Directors held Nov. 19, 1930, the Board voted to authorize and instruct the Executive Secretary to submit to the members for approval by letter ballot, amendments to the By-Laws making the fiscal year of the Association extend from July 1st to June 30th. The ballot was submitted to the members and was canvassed by the judges December 22, who reported that of the 710 ballots cast, 680 were for and 30 against the change. In accordance with provision of the ballot this change in fiscal year became effective July 1, 1931.

Application of New Rates for Dues Deferred

The Secretary announced that the Board of Directors, by unanimous ballot, instructed the Secretary-Treasurer to waive application of the new rates for dues, previously approved to become effective January 1, 1931, until the beginning of the new fiscal year, July 1, and to bill all members for the first half of the calendar year at the old rates. The Secretary also announced that, unless further action was taken, the new rates would become effective July 1, 1931.

Discussion followed, prompted by a realization of all those present that under present business conditions there was some question as to the advisability of increasing rates at this time. Following discussion it was unanimously voted to instruct the Secretary-Treasurer to make effective the new membership classifications and new rates for dues as of July 1, 1931.

Proposed Reduction of Salaries

The Chair announced that all Directors had received a letter from the Executive Secretary under date of April 30, and recommending a reduction in certain Association salaries effective May 1, 1931. On motion duly seconded, the question was referred to the Finance Committee for consideration and report at the annual Board meeting.

Time and Place of 1932 Convention

The Secretary made a brief report on invitations for the 1932 Convention and recommended that consideration of these invitations be deferred until the annual Board meeting. It was so ordered.

Time and Place of Annual Board Meeting

On motion duly seconded, it was voted to hold the annual Board meeting early in July at the call of the President, at a time and place to be determined by him after conferring with the Executive Committee.

On motion duly seconded, the meeting stood adjourned.

Respectfully submitted,

C. E. HOYT, *Executive Secretary.*

Minutes of Annual Meeting 1930-31 Board of Directors

AMERICAN FOUNDRYMEN'S ASSOCIATION
ROYAL YORK HOTEL, TORONTO, CANADA, JULY 9, 1931

President N. K. B. Patch presiding.

The following responded to roll call: President N. K. B. Patch, Vice-President E. H. Ballard; Directors B. H. Johnson, P. J. Krentz, S. W. Utley, F. L. Wolf, Frank J. Lanahan, Delos H. Wray, Fred Erb, R. M. Maull, D. M. Scott and C. E. Hoyt; Directors-elect T. S. Hammond, D. M. Avey, W. D. Moore and A. G. Storie; Technical Secretary R. E. Kennedy, and Past Presidents L. L. Anthes, R. A. Bull, B. D. Fuller and H. D. Miles.

Approval of Minutes

Minutes of the meeting of the Board held at Chicago, May 7, 1931, were read and, on motion, approved.

Report of the Executive Secretary

The Executive Secretary read his annual report to the Board. On motion, the report was accepted and ordered filed.

Report of the Treasurer

The Treasurer submitted his report, which included an unaudited statement of accounts of the Association as of date of June 30, 1931. On motion, the report of the Treasurer was accepted and ordered filed.

Director Utley, commenting on the report of the Treasurer, called attention to the fact that the par value of securities in the Reserve Fund now totals $50,500.00, and that the annual income from interest is $2,380.00. He then moved that it be the sense of this Board that the Reserve Fund as established is sufficient for Association needs, and that hereafter the interest on the Reserve Fund be not reinvested in securities but go into the operating fund. Motion seconded by Director Lanahan and carried.

Report of the Finance Committee

Vice-President Ballard, Chairman, submitted the following report:

> "The last official audit of the books of the Treasurer of the A. F. A. was made as of date of Dec. 31, 1930. The six months' period January 1 to June 30 cover the period between the closing date of the old fiscal year and the beginning date of the new fiscal year, July 1, 1931.
>
> "No official audit has been made of the books as of date of June 30, 1931, but the Finance Committee begs to report that it has examined the financial statements submitted by the Treasurer setting forth the financial condition of the Association as of date of June 30, which they have found satisfactory, and recommend that the official audit for the six months' period be included in the audit made at the end of the present fiscal year, June 30, 1932."

On motion duly seconded, the report of the Finance Committee was accepted.

Report of Technical Secretary

Secretary Hoyt moved that, as all Directors had received an abstract of the full report of Technical Secretary Kennedy, the reading of the report go over to the next meeting, as action on the recommendations in the report should be dealt with by the incoming Board.

Report of Executive Committee

The Executive Secretary submitted a report for the Executive Committee which, on motion, was accepted and ordered filed.

Report of Manager of Exhibits

The Manager of Exhibits read his annual report, which, on motion, was accepted and ordered filed.

Report of Divisional Activities Correlation Committee

Vice-President Ballard included in his report the recommendation

that a set of rules and regulations be adopted for governing the conduct of organized group activities.

Mr. Ballard, in concluding his report, moved that this committee, which now consists of the Vice-President of the Association as Chairman, and the chairman of each of the divisional groups, be enlarged to include two members of the Board of Directors to be appointed annually. Motion seconded by Director Krentz and carried.

Mr. Ballard then moved that the question of rules and regulations for the governing of divisional activities be referred to the Divisional Activities Correlation Committee to formulate a set of rules for the Board's consideration and acceptance. The motion was duly seconded and carried.

New Membership Classifications and Changes in Rates of Dues

The Executive Secretary submitted a report on the application of new rates of dues which became effective July 1 and requested an interpretation of the By-Laws re the status of subsidiary organizations of a company holding a Firm membership and paying annual dues of $25.00. Following discussion it was moved, seconded and carried that the matter be referred to the incoming Board for action.

Cooperation of Foundry Equipment Manufacturers' Association

The Executive Secretary reported having attended, on invitation, a meeting of the Foundry Equipment Manufacturers' Association on June 12, and he read a copy of the resolutions adopted on that occasion by the F. E. M. A. reaffirming the splendid spirit of cooperation always manifest in its relations with the American Foundrymen's Association and emphasizing especially the assistance, cooperation and cordial relations which the association has enjoyed with the Board of Directors and Manager of Exhibits.

President Patch invited the Secretary of the F. E. M. A., Director-Elect Avey, to say a word about the work of that association. In closing Mr. Avey said that he felt no greater cooperation could be wished than existed between the F. E. M. A. and the A. F. A.

It was moved and seconded that the resolutions be made a matter of record and that the Executive Secretary be instructed to acknowledge the resolutions and to extend to the officers and members of the F. E. M. A. the Board of Directors' sincere appreciation of the resolution adopted and their earnest hope for the continuance of the friendly and helpful relations existing. Motion carried.

Research Appropriations

Director Utley, Chairman of the Committee on Research Appropriations, reported that they had no recommendations to make for research appropriations at this time.

Secretary Hoyt reported that in accordance with the recommendation of the Research Appropriations Committee, reported at the meeting

of the Board of Directors May 7, E. J. Ash, Research Associate at the U. S. Bureau of Standards, and his superior at the Bureau, had been formally notified that no appropriation had been made for his services after Aug. 31, 1931.

Report of Election of Officers and Directors

The Executive Secretary reported that at the annual meeting of the Association held on the closing day of the annual convention at Chicago, May 7, 1931, the following were declared duly elected officers and directors of the Association, to take office in accordance with the provisions of the By-Laws, at the time of the next annual Board meeting:

For President to serve one year:

E. H. Ballard, General Electric Co., West Lynn, Mass.

For Vice-President to serve one year:

T. S. Hammond, Whiting Corp., Harvey, Ill.

For Directors, each to serve three years:

D. M. Avey, *The Foundry*, Cleveland, Ohio.
W. D. Moore, American Cast Iron Pipe Co., Birmingham, Ala.
N. K. B. Patch, Lumen Bearing Co., Buffalo, N. Y.
A. G. Storie, Fittings, Ltd., Oshawa, Ont., Canada.
Fred L. Wolf, Ohio Brass Co., Mansfield, Ohio.

Appreciation

The Executive Secretary reported that, with the adjournment of this Board meeting, the terms of office of Directors B. H. Johnson, P. J. Krentz, S. W. Utley and C. E. Hoyt would expire, and that to Director F. J. Lanahan had been accorded the privilege of expressing the appreciation of members of the Board for the services rendered by the above-named retiring Directors.

In beautiful language and well-chosen words, Director Lanahan performed this duty and then, turning to the Chair, said:

> "And to you, Mr. President—you have left a splendid heritage. I know of nothing with which I should like better to commemorate my associations with the A. F. A. than the address you made at the Chicago Convention. It was a splendid program for any association to adopt which expects to attain the highest ideal and the full maximum of accomplishment.
>
> "I am sure everyone feels it has been a joy to know you and it has been a wonderful thing to be able to work with you and for you. On behalf of the Association let me express to you as President our heart-felt gratitude for the splendid work you have done, and pass it on in proportionate measure to the Directors who go with you."

President Patch replied in part as follows:

"This has been a year somewhat different from many years that have passed for the Association. It has been a year faced with conditions which I hope are very temporary and are going to disappear in the near future. These conditions have brought before us many problems that might not have been so troublesome under normal conditions. However, I have enjoyed the work; I believe even more because there have been so many things in which I could help your Secretary and staff and add my little bit toward fostering the aims of the Association.

"Permit me to thank you, Mr. Lanahan, and all whom you represent, for the very kind sentiments expressed. I certainly appreciate them and shall long remember them. It has been a joy to work for the Association in the intimate way an officer does. I am going to find an inspiration in the memory of this past year.

"I want to assure you that I very much appreciate the cooperation I have had from the Board individually and collectively, from the men who have served on the different committees, from the staff in our Chicago office, and all who have helped me in my attempts to be of service to the Association.

"I know that I am passing the work along to a worthy successor, one who has shown during the past year a very real interest in Association affairs and who has given of his time, thought and energy without stint. We all feel, I know, that things are going to be in the best of hands for another year.

"I take a great deal of pleasure in introducing the new President and to assure him of my delight in giving my fullest cooperation during the next year and being of every assistance I can. What I have learned this year will, I hope, enable me to be of service to him. Mr. Ballard, I wish you every success in your office and look forward to a big year for you."

Mr. Ballard, in responding, said:

> "It may be ill-advised for an incoming President to say very much, for, after all is said and done, it is what he does and not what he says that tells the story. However, I want to take a moment to tell you that if your new President fails, it will not be because he does not exert himself to the utmost with the limited talents he has.
>
> "I pledge the best I have in the hope that the term of usefulness to our members will be on the ascending curve, and I hope that at the end of the year our point in the curve will be up rather than down. All I ask is your cooperation, and I will certainly give you the best that is in me."

Whereupon the final meeting of the 1930-31 Board of Directors was declared adjourned at 12:30 P. M., with the announcement that the new Board would convene immediately after luncheon.

Respectfully submitted,

C. E. HOYT, *Executive Secretary.*

Minutes of First Meeting 1931-32 Board of Directors

AMERICAN FOUNDRYMEN'S ASSOCIATION
ROYAL YORK HOTEL, TORONTO, CANADA, JULY 9, 1931

President E. H. Ballard presiding.

The following responded to roll call: President E. H. Ballard, Vice-President T. S. Hammond; Directors Frank J. Lanahan, Delos H. Wray, Fred Erb, R. M. Maull, D. M. Scott, D. M. Avey, W. D. Moore, N. K. B. Patch, A. G. Storie and F. L. Wolf; Executive Secretary C. E. Hoyt; Technical Secretary R. E. Kennedy; Past Directors B. H. Johnson, P. J. Krentz and S. W. Utley; Past Presidents L. L. Anthes, R. A. Bull, B. D. Fuller and H. D. Miles.

President Ballard introduced Vice-President T. S. Hammond and the new members of the Board, D. M. Avey, W. D. Moore and A. G. Storie, who, together with N. K. B. Patch and F. L. Wolf, were installed as Directors for terms of three years each.

Organization of New Board

The Chair announced that the first order of business would be the organization of the new Board and that he would appoint Directors Erb, Moore and Storie as members of the Nominating Committee to present nominations for the offices of Executive Secretary, Treasurer, Technical Secretary, Manager of Exhibits, Assistant Secretary-Treasurer, and four Directors to serve as members of the Executive Committee.

Report of Nominating Committee

Director Erb, as Chairman of the Nominating Committee, reported nominations as follows:

For Executive Secretary-Treasurer, C. E. Hoyt.
For Technical Secretary, R. E. Kennedy.
For Manager of Exhibits, C. E. Hoyt.
For Assistant Secretary-Treasurer, Miss Jennie Reininga.
For Assistant Managing Editor, Wm. W. Maloney.
For members of the Executive Committee: N. K. B. Patch, D. M. Avey, F. L. Wolf and F. J. Lanahan.

There being no further nominations, the Chair declared the nominations closed and it was moved and seconded that the unanimous ballot of the Directors be cast for the nominees submitted by the committee.

1931-32 Finance Committee

The Chair announced that, in accordance with action taken at the preceding meeting, the following would serve as members of the Finance Committee for the ensuing year: Past President N. K. B. Patch, Chairman; President E. H. Ballard, and Vice-President T. S. Hammond.

Committee on Research Appropriations

On motion, the President was authorized to appoint a Committee on Research Appropriations and later announced the following appointments: N. K. B. Patch, Chairman; T. S. Hammond, W. D. Moore and D. M. Scott.

Disbursement of Funds Resolutions

The following resolutions were read and unanimously approved by vote of the Directors:

"*Resolved*, that checks for the withdrawal of funds deposited in the name of the Association shall bear two signatures, as follows:

the President and the Executive Secretary-Treasurer, the Vice-President and the Secretary-Treasurer, or the President and the Vice-President.

"*Resolved*, that the resolutions required by the banks in which the funds of the Association are deposited, authorizing the withdrawal of funds, are hereby approved and adopted, and the Executive Secretary authorized to certify thereto.

"*Resolved*, that the Officers of the Association are hereby authorized to open an account in the convention city for a special convention checking fund, they to determine how this account shall be opened and the signatures required for the withdrawal of said fund.

"*Resolved*, that the Board authorize a Secretary-Manager's petty cash fund of $1,000.00, said funds to be reconciled at the end of each month by a full statement of expenditures.

"*Resolved*, that the President and Executive Secretary are authorized to employ such assistance as is deemed necessary to take care of Association activities, compensation for such services to be approved by the Finance Committee."

Salaries and Compensations

In submitting the report of the Finance Committee on salaries for the year beginning July 1, 1931, the Chairman announced that the formal communication of the Executive Secretary re certain salary reductions, considered at the Directors' meeting May 7 and referred to the Finance Committee, had received due consideration and they now made the following recommendations which were unanimously approved:

Salary of Executive Secretary-Treasurer, $6,000.00 per annum.

Salary of Technical Secretary, $6,600.00 per annum.

Salary of Manager of Exhibits, $7,500.00 per annum.

Salary of Assistant Secretary-Treasurer, $3,600.00 per annum.

Salary of Assistant Managing Editor of *Transactions*, $3,600.00 per annum.

(*See Note to summary of Finances, page vi, recording reductions made in above salaries since January, 1932.*)

Members of the committee: N. K. B. Patch, Chairman, E. H. Ballard and T. S. Hammond.

Treasurer's and Assistant's Bond

It was moved that bonds to the amount of $5,000.00 should be taken out for the Treasurer and Assistant Treasurer, the premium to be paid by the Association. Motion seconded and carried.

Appropriations for Prizes

On motion duly seconded and carried, the Board of Directors authorized the offering of prizes for apprentice molding and pattern-making contests at the 1932 Convention, provided the Board of Awards voted the necessary funds for said prizes.

Resolution Authorizing Paying of Committee Meeting Expenses

By vote of the Directors, the following resolution was adopted:

"*Resolved*, that the Treasurer be authorized to reimburse the traveling expenses of Directors and committee members for attendance at any regularly called Board or Committee meetings, with the following exceptions:

"When meetings are held in conjunction with meetings of other committees or associations, the Treasurer is authorized to determine what proportion of the expenses of attending such meetings shall be paid by the Association.

"No expenses shall be paid to Directors or committee members for attendance at meetings held during the week of the annual convention of the Association unless specially authorized."

Research Appropriations

The Committee on Research Appropriations recommended an appropriation of $750.00 for the work of the Committee on Foundry Sand Research for the coming year, and an appropriation of $100.00 as a contribution to the general expenses of the Joint Committee on Investigation of the Effects of Phosphorus and Sulphur in Steel.

Committee Appointments

On motion duly seconded, the President was authorized to make all appointments for standing and special committees not provided for in the By-Laws or by special act of the Board.

Report of Committee on International Relations

Director Avey, Chairman of the Committee on International Relations, submitted his report and authorization was given the committee to continue its negotiations with the International Committee of Foundry

Technical Associations in the matter of exchange papers, and to continue its contacts and negotiations with tourist companies in developing plans for the attendance of the American delegation at the next World's Congress scheduled for Paris in September, 1932.

Inter-Society Relation Policies

Advisory Board member, Major R. A. Bull, was present on invitation to discuss Association policies on inter-society relations. Major Bull stressed the point that every effort should be made to avoid duplication of work, between not only the A. F. A. and trade associations of the foundry industry but also the A. F. A. and all allied technical and engineering associations and societies, and that our inter-society relations should be developed along the lines of fullest cooperation to the end that the program of activities of all allied societies and associations would avoid any unnecessary and uneconomical over-lapping.

Report of Technical Secretary

The next order of business was discussion of the extended report of Technical Secretary Kennedy, which had been presented in abstract at the previous meeting and referred to the new Board for further consideration. This report, which was discussed at length, included announcement that a Foundry Committee under the Machine Shop Practice Division of the American Society of Mechanical Engineers had been organized to sponsor foundry programs at A. S. M. E. meetings, or at joint meetings of the A. S. M. E. and such organizations as the A. F. A. Programs for these meetings would deal with such subjects as casting design and foundry equipment problems.

It was announced that the first session would be held at the annual meeting of the A. S. M. E. in December, 1931. The personnel of this new A. S. M. E. committee is made up largely of men who are also members of A. F. A.

Major Bull, in commenting on this report, stated that a great many engineers were considering the matter of casting design who never had done so before, and he urged the A. F. A. to do all it could to encourage this type of cooperation.

President Ballard expressed the opinion that the A. F. A. should make a supreme effort to organize joint meetings between men of the foundry industry and members of engineering societies throughout various sections of the country.

Regional Meetings

Secretary Kennedy announced that no definite plans had been made for a regional meeting the coming year but that it had been suggested, in lieu of such regional meetings as were held in 1929 and 1930, that meetings be held of a less elaborate nature in conjunction with local and district associations, limited possibly to an afternoon and evening. President Ballard suggested it be made known to the various organizations

throughout the country that the A. F. A. stands ready to assist in carrying out such a program.

Membership Classifications and Rates of Dues

Discussion developed the need of some interpretation and possibility of an amendment to the By-Laws that would definitely establish the status of subsidiary plants of Firm member organizations. Pending such amendment, the Board voted unanimously to instruct the Secretary to make the following announcement and to extend membership privileges thereon:

> "Only one membership fee of $25.00 will be required of any firm or corporation, and Affiliated membership privileges at the minimum rate of $7.50 per annum shall be available to all persons at the plant where the Firm membership is held. At other plants of the same company, or subsidiary companies operating foundries, either Firm membership at $25.00 or Plant membership at $15.00 may be held, and under both classes Affiliated membership at $7.50 shall be available to all men in said plants."

Museums of Science and Industry

Secretary Hoyt reported that committees organized by the A. F. A. to cooperate with the New York Museum of Science and Industry in New York and the Rosenwald Museum of Science and Industry in Chicago, were cooperating in the preparation of permanent foundry exhibits for these institutions. President Ballard and Director Avey, members of the New York committee, reported on progress made.

Resolution on Death of R. J. Doty

Director Avey, Chairman of the Committee on Resolutions, submitted the following resolution which was unanimously adopted:

"*Whereas*, Raymond J. Doty, Plant Manager of the Reading Steel Casting Company, Reading, Pennsylvania, died February 24, 1931, and

"*Whereas*, Mr. Doty throughout his business career had been an active and effective worker in the interests of the American Foundrymen's Association in the promotion of its technical research relating particularly to sand tests and steel casting technique, and

"*Whereas*, Mr. Doty was a nominee for Director of the American Foundrymen's Association, subject to election for a three-year term starting in July, 1931, now therefore

"*Be It Resolved*, that these resolutions appear upon our records and that a copy be transmitted to Mrs. Doty and her family with the profound sympathy and respect of the Board of Directors of the American Foundrymen's Association."

1932 Convention City

Secretary Hoyt submitted a report on invitations received for holding

the 1932 convention and exhibit, giving information as to data obtained and facilities offered.

Following discussion, it was moved, seconded and carried that the Board authorize the President to name a committee with power to act in naming the place and time of the 1932 convention and exhibit of the Association, and to authorize the Executive Secretary to make the necessary contracts when the convention city had been selected.

The Directors whose terms of office expired on this date expressed the pleasure and satisfaction they had derived from service on the Board, and Mr. Utley in his closing remarks urged that members of the Board and all those in any way responsible for the conduct of Association affairs get the attitude that the benefits of membership to organizations and individuals were many times greater than the cost of annual dues. Addressing the new members he said:

> "I have been a member of many boards, but on none of them have I found the spirit and the whole-hearted desire to unselfishly work for an industry that I have found on this Board. I can say from experience that if you attend the meetings and give everything asked for by the Association, you will get a great deal of pleasure and satisfaction out of the opportunity that will be yours of serving A. F. A."

Secretary Hoyt then introduced E. R. Powell, Managing Director of the Toronto Convention and Tourist Association, and B. A. Neale, Manager of the Royal York Hotel, Toronto, at whose urgent invitations the meetings of the Directors had been called in Toronto. Mr. Powell expressed the hope that an annual convention of the A. F. A. would be held in Toronto in the near future.

President Ballard responded, thanking Mr. Powell and the management of the hotel for hospitality shown the Directors and their wives, following which he announced the final adjournment of the 1931 annual meeting of the Board at 6:30 P. M., to meet again at call of the President.

Respectfully submitted,

C. E. HOYT, *Executive Secretary.*

Minutes of Executive Committee Meeting 1931-32 Board of Directors

AMERICAN FOUNDRYMEN'S ASSOCIATION
HOTEL ASTOR, NEW YORK, Nov. 19, 1931

President E. H. Ballard presiding.

The following responded to roll call: E. H. Ballard, T. S. Hammond, C. E. Hoyt, Frank J. Lanahan, Dan M. Avey, N. K. B. Patch and F. L. Wolf. Absent, none.

Financial Statement

On motion duly seconded, the financial statement mailed all members of the Executive Committee on November 12, showing receipts and expenses from July 1 to Nov. 1, 1931, and estimated receipts and expenses to December 31, was accepted and ordered filed.

Withdrawal of Securities Resolution

On motion duly seconded, the following resolution required by the bank was unanimously approved:

"Resolved, that all withdrawals of securities and accumulated interest in the Sinking Fund of the Department of Exhibits of the American Foundrymen's Association, held by the Trust Department of the Harris Trust & Savings Bank, Chicago, shall require two signatures as follows:

The President and the Executive Secretary-Treasurer, or

The Vice-President and the Executive Secretary-Treasurer, or

The President and the Vice-President.

Surety Bond

On motion duly seconded, the officers were instructed to take out a National Surety Bond to cover losses from forged endorsements, altered checks, etc.

Salary Reductions Recommended

The Secretary submitted a statement showing all salaries authorized at the annual Board meeting on July 9, for the fiscal year ending June 30, together with a statement of all clerical salaries in the Chicago office, and recommended that the Executive Committee authorize horizontal reductions in all salaries and clerical compensations.

On motion duly seconded, the recommendations were referred to the Finance Committee with power to act.

Membership Report

The Secretary submitted a report on membership for the period July 1 to Nov. 16, 1931, and gave the book membership as of that date as 2053, and the total receipts from dues for the same period as $23,536.78.

Philadelphia Auditorium Contract

On motion duly seconded, a contract agreement with the City of Philadelphia for the use of the Municipal Auditorium for a Convention and Exposition the week of May 2 to 6, 1932, was approved.

On motion duly seconded, the price of space for the 1932 Exhibit was fixed at $1.00 to $1.25 per square foot, the maximum rate applying to preferred corner locations.

Advisory Committee on Exhibits

President Ballard announced appointment of an Advisory Committee of fifteen on Exhibits. On motion, the appointments were approved and the Secretary instructed to notify the members thereof.

Technical Committee Organization Plan

The general Technical Committee Organization Plan, an outline of which had been submitted to all members of the Executive Committee, was approved with such minor modifications as were recommended and approved by a majority vote of the members of the Divisional Activities Correlation Committee.

Nonferrous Division

The special Rules and Regulations for the conduct of the Nonferrous Division, an outline of which had been submitted to the members of the Executive Committee, were approved with such changes as had been proposed by the Technical Secretary and members of the Nonferrous Division Advisory Committee.

Change in Name of Publication

On motion duly seconded, it was voted to change the name of the monthly publication from *Transactions and Bulletin* of the American Foundrymen's Association, to *Transactions American Foundrymen's Association.* A change in cover design also was approved, to become effective with the January, 1932 issue.

The issuing of a series of popular type circulars, similar in character to the circular entitled "To Arms!" and for the purpose of increasing Association consciousness, was approved.

Annual Exhibitors' Dinner

On motion, it was voted to recommend to the Foundry Equipment Manufacturers' Association that the Annual Exhibitors' Dinner be dispensed with at the 1932 Convention.

Cooperation of A. S. M. E. Groups

The Executive Secretary reported that the Materials Handling, Management and Maintenance Divisions of the American Society of Mechanical Engineers had accepted an invitation to meet in joint convention with the A. F. A. at Philadelphia in 1932.

The Secretary also reported negotiations with the American Gas Association and their decision to cooperate in securing exhibits of gas-burning equipment.

In view of this new alignment of cooperating societies, the name "Foundry and Industrial Exposition" was approved for the 1932 Exhibit.

The meeting of the Executive Committee had been preceded by a

meeting of the Board of Awards and the meeting was adjourned that all members might accept the invitation of Professor Rowe to visit the New York Museum of Science and Industry and view the foundry exhibit which had been partially installed.

Respectfully submitted,

C. E. HOYT, *Executive Secretary.*

Minutes of Meeting of Board of Awards

AMERICAN FOUNDRYMEN'S ASSOCIATION
HOTEL ASTOR, NEW YORK, Nov. 19, 1931

Members present: N. K. B. Patch, Chairman, Fred Erb, S. T. Johnston, S. W. Utley, A. B. Root, Jr., L. W. Olson and G. H. Clamer. Absent, none.

The Chair announced that the first order of business would be consideration of 1932 medallists. It was moved and unanimously carried that two major awards be made in 1932.

It was moved and unanimously carried that the Board of Awards recommend to the Board of Directors that a major award of the American Foundrymen's Association be conferred upon LaVerne W. Spring, Chief Chemist and Metallurgist, Crane Co., Chicago, and a John A. Penton gold medal be presented to him at the 1932 annual convention.

It was moved and unanimously carried that the Board of Awards recommend to the Board of Directors that a major award of the American Foundrymen's Association be conferred upon Dr. H. W. Gillett, Director, Battelle Memorial Institute, Columbus, Ohio, and a W. H. McFadden gold medal be presented to him at the 1932 annual convention.

On motion duly seconded it was voted to make funds available for apprentice contests in steel molding, gray iron molding and pattern making, the first prizes to be of $50.00 value, second prizes $25.00 value and third prizes $10.00 value.

On motion duly seconded it was voted to authorize an appropriation of $10.00 from the Award Interest Fund for a special lecturer at the annual meeting in the event the Committee on Program and Papers had need of such a fund.

On motion duly seconded the officers of the Association were author-

ized to withdraw funds from the Award Interest Account on interest dates sufficient to defray the authorized expenses and appropriations of the Board of Awards.

There being no further business, the meeting adjourned.

Respectfully submitted,

C. E. HOYT, *Executive Secretary*

Minutes of Meeting of 1932 Nominating Committee

A meeting of the Nominating Committee of the American Foundrymen's Association was held at Cleveland, Jan. 15, 1932, attended by the following members: Past Presidents S. T. Johnston and N. K. B. Patch; elected members M. A. Blakey, H. F. Seifert, Frank A. Sherman and Ralph H. West.

The Chair announced that the meeting had been called for the purpose of nominating officers and directors in accordance with the provisions of the By-Laws. Reports were received from members who had responded to a general invitation to make nominations for officers and directors. The nominations of the members of the committee were then received and the following nominations made:

For President to serve one year:

T. S. Hammond, President, Whiting Corp., Harvey, Ill.

For Vice-President to serve one year:

Frank J. Lanahan, President, Fort Pitt Malleable Iron Co., Pittsburgh.

For Directors to serve three-year terms each:

E. H. Ballard, General Foundry & Pattern Shop Superintendent, General Electric Co., West Lynn, Mass.

H. Bornstein, Director, Testing & Research Laboratories, Deere & Co., Moline, Ill.

S. B. Cuthbert, Superintendent of Foundries, Edgar Thomson Works, Carnegie Steel Co., Braddock, Pa.

David Evans, President Chicago Steel Foundry Co., Chicago.

Franklin G. Smith, President, Osborn Mfg. Co., Cleveland.

The Executive Secretary was instructed to secure the acceptances of all candidates and then submit the report of the Nominating Committee to the membership at large.*

Respectfully submitted,

C. E. HOYT, *Executive Secretary*

* Report mailed to members Jan. 29, 1932.

Some Notes on the Structure of the British Foundry Industry*

By Vincent C. Faulkner,† London, England

Abstract

The author states that, as a result of the fiscal policy of free imports which has been in operation in Great Britain for about a century, and because of the considerable export business, the foundry industry is infinitely more varied than that of any other country. While the industry is inadequately represented among the great national employers' organization, there are several organizations of employers. The trade union is represented by the National Union of Foundry Workers, one of the oldest amalgamations of work people in the world. The outstanding technical and scientific organizations are the Institute of British Foundrymen and the British Cast Iron Research Association. The apprentice situation and the standardization of castings are discussed, together with factory regulation and inspection. The author then reviews briefly the situation as to foundries in the various branches of the industry.

Introduction

1. Because of the fiscal policy which has been in operation in Great Britain for about a century, the foundry industry is infinitely more varied than that of any other country in the world. Its system of free imports has had a profound influence upon the equipment of the industry, and thus one finds in most modern foundries a well-blended mixture of British, American, French, German and Belgian plant. On the other hand, there exist foun-

* Annual exchange paper of the Institute of British Foundrymen.

† Editor, *Foundry Trade Journal*, and past-president, Institute of British Foundrymen.

dries which are virtually 100 per cent British, American or French in their equipment.

2. Another phase of the British foundry industry is that during this period a very considerable export business has been maintained, which has resulted in the creation of foundries making castings which are never used in the country, such as those for the preparation of tea, sugar, rubber, oil and for the market for various types of mining machinery. Thus, from the dual aspect of variety of equipment and production, Great Britain probably is unique.

COMMERCIAL ORGANIZATION OF THE INDUSTRY

3. Because of the great variety of the production of British foundries—associated perhaps with the inherent individualistic characteristics of the average Britisher—the industry is inadequately represented among the great national employers' organizations.

4. The most important organization for treating with the labor unions is the Engineering Employers' Federation, which certainly consults the leading foundry employers' association—the National Ironfounding Employers' Federation, of which the chairman is James Smith of South Shields. Naturally, the powerful shipbuilding organization also is prominent in questions affecting the working conditions in those foundries attached to their establishments.

5. There is, however, one branch of the industry which has been reasonably well organized for about twenty years, and that is the group manufacturing builders' castings—stove grates, fallpipes and the like. The credit of this is due very largely to Ex-Bailie John King, of Glasgow. In recent years, however, the association—the National Light Castings Association—began to suffer from disintegration, and in January this year it was superseded by the British Ironfounders' Association, which is presided over by a prominent legal authority, Sir Gervais Rentoul, K. C.

6. Of the district associations, the most active is the Welsh Engineers' and Founders' Association, which is fortunate in possessing a very energetic and enthusiastic chairman in Fred Taylor, J. P., while those located in Manchester, Sheffield, Leicester, Newcastle and Glasgow are useful in acting as a liaison with the unions and other employers' federations.

THE TRADE UNIONS

7. The National Union of Foundry Workers, the principal trade union of the industry, is one of the oldest amalgamations of work people in the world, having celebrated its centenary some twenty years ago. Its president is the Right Honorable Arthur Henderson, P. C., His Majesty's Minister for Foreign Affairs.

8. Although this union is fairly comprehensive, there are several others which look after the interests of the molders in the light castings industry, the fettlers and the pattern makers. While these unions are extremely powerful in the country, taken as a whole, they have failed to get any real foothold in the newer industrial area which is growing up around London.

TECHNICAL AND SCIENTIFIC ORGANIZATION

9. Although the employers' side of the industry is not, to our mind, organized on a satisfactory basis, its technical aspirations are taken care of more adequately. Primarily, in the Institute of British Foundrymen, which has been established for about a quarter century, it possesses a means of expressing its wishes on a truly national basis.

10. The membership, numbering close on 2000, is drawn from every phase of foundry activity, from prominent foundry owners down to the working molder, so that the Institute represents a true cross-sectional picture of the industry. Before a dozen branches and sections, about a hundred papers are submitted annually for discussion, and in addition no less than fifty works visits are organized.

11. It is the recognized channel for international cooperation in foundry matters, and it has a profound influence on the technical development of the industry. Because it possesses a Royal Charter, it is prevented from trading in any form, having a special *locus standi* in law. Therefore, unlike the various national technical associations of other countries, it is precluded from organizing trade exhibitions.

12. Research work for the industry is conducted on a cooperative basis through the British Cast Iron Research Association. Although only about seven years old, this organization is thoroughly established as the recognized medium for providing the gray iron and malleable sections of the industry with fundamental

and applied research work. While it does not possess a suite of well-furnished laboratories, it has surrounded itself with a highly-trained personnel which, under the able direction of J. G. Pearce, M. Sc., assisted by Dr. A. L. Norbury, carry out investigations in the metallurgical departments of the universities, their own laboratories and in the shops of member firms.

13. Up to the time of writing, the association has received generous monetary help from the government and invaluable scientific advice from the National Physical Laboratory and the various universities and technical colleges. The two outstanding developments within the organization are, a balanced-blast cupola and a non-growth gray iron.

AUXILIARY ORGANIZATIONS

14. Because of the quasi-legal inability of the Institute of British Foundrymen and the possibility of any local exhibition authority deciding to stage a foundry exhibition, the principle equipment and supply houses in 1925 formed an association to regulate matters in this connection through cooperation with the I. B. F. and foreign associations. This association, the Foundry Trades' Supply and Equipment Association, Limited, which is now presided over by D. Howard Wood, has had a prosperous career. It has already staged two successful exhibitions, in 1926 and 1929, and fulfills many useful functions in promoting coordination of effort within the industry.

15. Other associations which contribute to the technical development of the industry are the British Engineering Standards' Association, the Iron and Steel Institute, the Institute of Metals and the British Nonferrous Metals Research Association.

RECRUITMENT AND TRAINING OF PERSONNEL

16. The old-fashioned system of indentured apprenticeship has virtually disappeared, and efforts now are widespread to create adequate substitutes for its replacement. These efforts include the better adaptation of evening classes to the needs of entrants to the industry; the establishment of nationally-recognized "trade" and "professional" certificates, and the institution by the larger concerns of "schools" within the works.

17. Insofar as scientifically-trained workers are concerned,

there is probably a glut at the moment, and because of trade depression there is difficulty with their absorption by the industry. Most of the men available, however, need a short period of practical training before they are of real worth, and the incidence of this period creates difficulties both for the impoverished works and the recruit to industry.

18. While the modern substitutes for indentured apprenticeship may be found to be satisfactory, as the average present-day boy has received a better preliminary training than his father, yet we doubt whether he will become as a proficient a craftsman, due to the operation of the national labor exchanges and unemployment insurance acts.

19. Under modern conditions, the moment a man is out of employment, he registers at the local exchange, which makes an effort to place the man locally. If they are unsuccessful, then, after a short period, the unemployed workman receives his out-of-work benefit, provided he has paid a sufficient number of weekly premiums. Before the pasing of the acts, the unemployed or the ambitious molder went "on tramp," seeking both work and wider experience. Those conditions have gone and they will never return.

RATIONALIZATION THROUGH GROUPING

20. Within the last few years several efforts have been made to "rationalize" sections of the industry, and more are foreseen for the near future. The largest organization has been created within the light castings industry, under the title of Allied Iron-founders, Limited. It controls about twenty firms and is gradually segregating like manufactures into the most conveniently located shop coming under its control.

21. The second great group is Agricultural & General Engineers, Limited, which will possess about eight foundries. The major effort of this concern has been, up to now, the coordination of its selling activities throughout the world.

22. The third group also is in the agricultural line of business. It is comparatively new but has made an initial effort in concentrating some of its foundry activities by closing down one works and centralizing the manufacture of castings in one of its shops in East Anglia.

STANDARDIZATION OF CASTINGS

23. Under British conditions, standardization is not and cannot be the same problem as in America. Before a casting or range of castings can be standardized, one must take into consideration the following factors:

(a) A vast percentage of British business is in the export markets of the world, which insist on their own standards.

(b) The creation of standard types places a powerful weapon in the hands of foreign competitors operating in the domestic market, and these competitors often have lower standards of living than has Great Britain, which may facilitate the entry of their goods.

(c) In view of rapid, modern developments, the creation of standards may place industry at a discount, as the buyers regard specifications as the postulation of the best an industry has to offer.

STANDARDIZATION OF RAW MATERIALS

24. Serious efforts have been made to place the purchase of raw materials on a scientific basis, and it is normal practice among the larger foundries to buy pig iron, coke, sands, coal dust and even core oils to definite, specified chemical and physical requirements. The coloring of patterns now is being standardized, and it is anticipated that the final specification will differ from the American by the replacement of black by some color which will contrast strikingly with the black sand of the average foundry floor.

FACTORY REGULATIONS AND INSPECTION

25. The Home Office, through the Factory Inspection Department, imposes almost annually upon the foundry an increasingly large number of regulations designed to safeguard the health and welfare of the employees. Frequent visits from the district inspectors make the evasion of any of these regulations difficult.

26. The regulations embrace the systematic testing of all lifting tackle, the guarding of all machinery in motion, the extraction of dust from all grinders and sand-blast, while the distance any person may work in the neighborhood of the old-fashioned tumbling barrels is laid down, as is also the period between the cleaning of interior walls.

THE STEEL FOUNDRY INDUSTRY

27. It is said that Hadfields, Limited, of Sheffield, is the largest steel foundry in the world. Whether this is true or not, it is certainly of very great dimensions. Its main specialty is, of course, manganese steel, of which the chairman of the company, Sir Robert Hadfield, F.R.S., is the inventor.

28. Other firms of considerable size situated in Sheffield, are Edgar Allen & Company, Limited; Thos. Firth & Sons, Limited; the English Steel Corporation; Jessop & Company; and S. Osborne & Company, Limited, all of which concerns have achieved international reputations for the high quality of their productions. In Scotland there is very considerable trade done in its twenty-six steel foundries, England possessing about eighty-five.

29. There is no common method of melting used in British foundries, and the acid open-hearth, baby Bessemer, electric and crucible are all in use. The product of the small converter is accepted by all the national purchasing authorities as being equally good as electric steel. We do not know of any steel castings now being made in acid-lined electric steel furnaces, although a firm in North Yorkshire may provide the exception.

30. The high-frequency induction furnace is being used in one Southern foundry (Lake & Elliot, of Braintree) for the man-

FIG. 1—AERIAL VIEW OF EAST HECLA WORKS OF HADFIELDS, LTD., SHEFFIELD. THIS PLANT IS STATED TO CONTAIN THE LARGEST STEEL FOUNDRY IN THE WORLD. MOST OF THE BUILDINGS SHOWN HERE ARE FOUNDRY SHOPS.

FIG. 2—ONE OF THE LIGHT CASTINGS BAYS OF EAST HECLA WORKS OF HADFIELDS, LTD., SHEFFIELD.

ufacture of stainless and electro-magnetic steel castings, and is giving excellent service at a production cost comparable with that of, say, a 2-ton electrode electric furnace.

31. As Great Britain is subjected to the full blast of Continental competition, British steel foundries are forced to practice the most rigid economies in manufacturing methods. Detailed attention is given to preparation and handling of sand to the molders.

32. The welding of small defects in steel castings is not looked on with favor by buying authorities, and special permission invariably has to be obtained. Electric welding, using coated electrodes of specified composition, varying with each grade of casting, is the most popular type of outfit.

33. Loam, composition, dry sand and green sand all are used in the making of molds, while there is a lively competition between Belgian and British sand as the principle basis. Synthetic sand—that is, a mixture of pure silica sand and clay—is not extensively employed. Mold conveyors, beyond a length of roller pathway, have not yet been installed.

MALLEABLE IRON FOUNDRIES

34. Although the consumption of malleable castings per head of population is probably lower in Great Britain than in any of the larger industrial countries, there are no less than 130 individual plants established. The best-known is Ley's Malleable Casting Co., Limited, of Derby, which is the largest malleable iron foundry in Europe. It manufactures American black-heart mal-

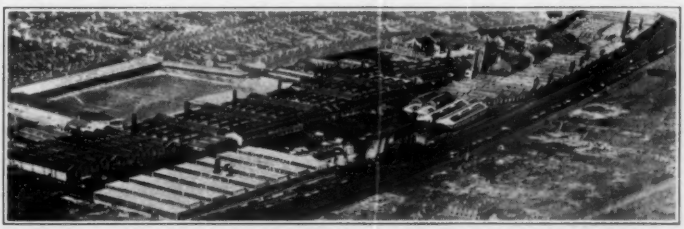

FIG. 3—THE LEYS MALLEABLE CASTINGS CO. LTD., DERBY, LARGEST MALLEABLE IRON FOUNDRY IN EUROPE. THIS PLANT OCCUPIES AN AREA OF THIRTY ACRES.

leable, and in this detail differs from most British concerns, which operate on white or Réaumur iron. All the melting and heating operations are carried through by the use of pulverized fuel, while for molding, sandslingers pulling four stripping machines in their wake are largely employed.

35. Another foundry utilizes the residual heat from steel making in the electric furnace as an aid to the economic melting of a synthetic mixture of steel turnings, ferrosilicon and anthracite for black-heart malleable. The principal white-heart manufacturers still use the cupola, which, because of its ability to give metal continuously, helps to secure a comparatively large output from restricted floor space.

36. At the moment, much attention is being devoted to rotary pulverized-fuel-fired furnaces of the Brackelsberg and Sesci types. One installation is working with initial success in Yorkshire, and others are almost ready to begin operations. Insofar as European conditions are concerned, the rotary pulverized-fuel-fired furnace is unique in being the only melting method ever offered to the foundry industry which claims the same low cost of melting as in the cupola.

37. The malleable iron foundry of Crane-Bennett, Limited, an allied concern of the Crane Company, Chicago, is one of the most intelligently designed foundries in Europe. The raw materials, coke and pig iron, are touched by human hands only for weighing, while the backing sand is prepared and distributed by a completely automatic system, except for moisture content. Molds are machine-made and assembled on eight roundabouts. Metal is brought in ladles suspended from an overhead runway.

38. Between the roundabouts, and running the whole length of the shop, is an apron conveyor which takes the sand and hot castings up a height where separation is effected by feeding onto an inclined grate. The sand falls into the boot of an elevator for re-preparation and cooling, while the castings are fork-handled into conveniently-situated, wheeled wrought-iron containers for transport into the adjoining hand-barreling and annealing shop.

39. It will be noted that no attempt is made to convey the cores to the molders, a factor which under European conditions often results in useless complications and little if any economy in working.

NONFERROUS FOUNDRY WORK

40. Where nonferrous foundries have been able to specialize on productions involving heavy expenditure on plant, control and a world-wide selling organization, the success achieved has been notable. For instance, manganese-bronze (high-tensile brass) propellors are made in London by J. Stone & Company, Limited, and other companies, and are exported to every corner of the earth.

41. Other concerns making valves (Dewrance & Co.) and bearings (Glacier Metal Co., Limited) have little difficulty in maintaining full shops, no matter what the conditions of general trading may be. A foundry in Yorkshire—David Brown & Sons, Limited, of Huddersfield—has been extremely successful in perfecting a system of centrifugal casting of bronze gear-wheel blanks.

42. In recent years, small oil-fired reverberatory furnaces have found increasing favor for nonferrous melting. This probably has been due in some measure to decreases in the price of the virgin metals and oil fuel. When the raw materials of the nonferrous foundry were expensive and erratic in price, a mistake in buying was sufficient to outweigh any reasonable economies in melting practice. The electric furnace is used also, the Ajax-Wyatt and the Ajax-Northrup being the most popular types.

43. The Birmingham Aluminium Casting Co. has probably the largest output of any light-alloy foundry in Europe. An associated company, Sterling Metals Co., Limited, easily leads the field as the largest producer of magnesium castings in England, with a

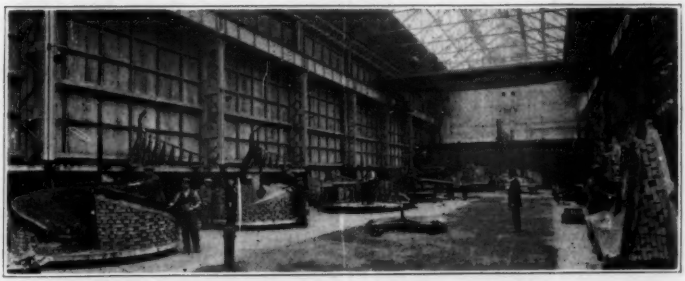

FIG. 4—VIEW OF PROPELLOR FOUNDRY OF J. STONE & CO., LTD., DEPTFORD, LONDON. MOLD DRYING OVENS ARE TO BE SEEN AT THE END OF THE SHOP.

FIG. 5—PART OF FOUNDRY OF BIRMINGHAM ALUMINIUM CASTINGS CO., LARGEST MANUFACTURERS OF LIGHT ALLOY CASTINGS IN EUROPE.

monthly production varying between 40 and 45 tons. To visualize just what this means, similar castings made in gray iron would weigh approximately 200 tons. Molding is carried out by a sandslinger, and sulphur is incorporated in the sand used.

44. Great progress has been achieved recently in the production of Alpax or silumin alloy. This, it will be remembered,

FIG. 6—ANOTHER OF THE SHOPS OF THE BIRMINGHAM ALUMINIUM CASTINGS CO.

FIG. 7.—ELECTRON FOUNDRY OF STERLING METALS, LTD., COVENTRY. LARGEST MANUFACTURERS OF MAGNESIUM CASTINGS IN GREAT BRITAIN. A SANDSLINGER IS USED FOR MOLDING.

contains 88 per cent of aluminum and 12 per cent silicon. It is used for internal fittings in submarines, doors for subway railroads, and motor coaches. The new R. R. (Rolls-Royce) alloys also have met with success, having been used in the Schneider Race seaplanes which won the trophy for Great Britain.

PIPE FOUNDING

45. The pipe business has been concentrated into the hands of less than half a dozen firms. They represent true pictures of simple vertical trustification, as they possess their own blast furnaces, iron ore mines, coal pits, coke ovens and perhaps even their own limestone quarries.

46. The largest maker of cast-iron pipe in Europe is the Stanton Ironworks Co., Limited, with an output of over 300,000 tons per annum. A large percentage of this production is made by the DeLavaud Process, which incorporates a system of centrifugal casting under specified methods of mold filling.

47. At the time of writing, the Staveley Coal & Iron Co., Limited, are putting into operation a large plant for the manufacture of sand-spun cast-iron pipes, a method developed by the American Cast Iron Pipe Co. of Birmingham, Ala. The products from these works find a ready market throughout the world, and about $7,500,000 is the value of the annual export business.

AUTOMOBILE FOUNDRIES

48. Automobile foundries have not yet assumed an importance analagous to their counterparts in the U. S., but commendable attempts have been made toward their complete mechanization. The most outstanding example is that of Morris Motors, Limited, of Coventry, where conveyors are used for getting the raw materials to the charging floor of the platform, where hand charging of the cupolas is considered an essential. This last phase is normal British practice for automobile foundries. Conveyors are employed for handling both molding and core sands.

49. In this connection, it is interesting to note that it is usual in British practice to dry incoming core sand before mixing with oil. Continuous drying stoves are used and, when the molds are cast, they are immediately passed into a ventilated hood in order to rid the atmosphere of noxious fumes.

FIG. 8—SPUN CAST-IRON PIPE AND CONCRETE PLANTS OF STANTON IRON WORKS CO., LTD., LARGEST MANUFACTURERS OF CAST-IRON PIPE IN EUROPE.

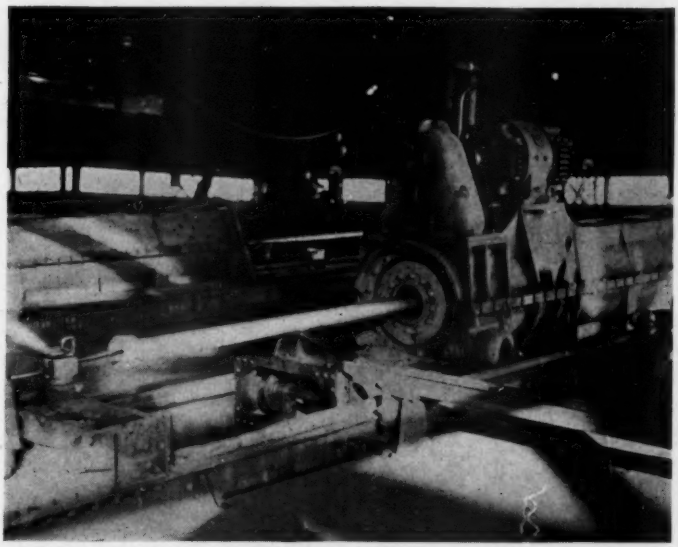

FIG. 9—DELAVAUD CENTRIFUGAL CAST-IRON PIPE PLANT INSTALLED IN WORKS OF STANTON IRON WORKS, LTD.

50. At the moment, two important developments are taking place in this industry. At Dagenham Docks, situated between London and the North Sea, Henry Ford & Son are constructing new works, including a blast-furnace plant, while at the Austin works in Birmingham a thorough revamping of the foundries is taking place, without interfering with production.

LIGHT CASTINGS

51. Until a few decades ago, the light castings industry has centered in Falkirk in Scotland, and in the Midlands. Today, however, representative foundries are to be found in all districts, with a general tendency toward a gravitation southward. In Scotland it has been customary for several decades to buy pig iron from Middlesbrough, but recently recourse has been made to Continental and Indian pig iron.

52. Some of the firms engaged in this section of the industry are extremely old. Probably the best-known are the Carron Company and the Falkirk Iron Co. In England, a very successful grouping has been organized under the title of Radiation, Limited.

53. Great progress has been made in recent years in the development of the wet process of enameling. In the rain-water

FIG. 10—METROPOLITAN-VICKERS ELECTRICAL CO., TRAFFORD PARK, MANCHESTER. PART OF NO. 1 IRON FOUNDRY, SHOWING CASTING PITS.

goods section, the number of patterns required before a foundry can be said to be in a position to fulfill any demand placed by the merchants is in the region of 5000 to 7000. Bath tubs also are made to an almost bewildering number of types and sizes.

54. The principal radiator foundries are American in origin, and their methods follow the practices characteristic of that country. Because of the inherent preference for the open coal fires for domestic heating, and their modern substitutes, the gas and electric fires, the radiator business has not yet assumed the

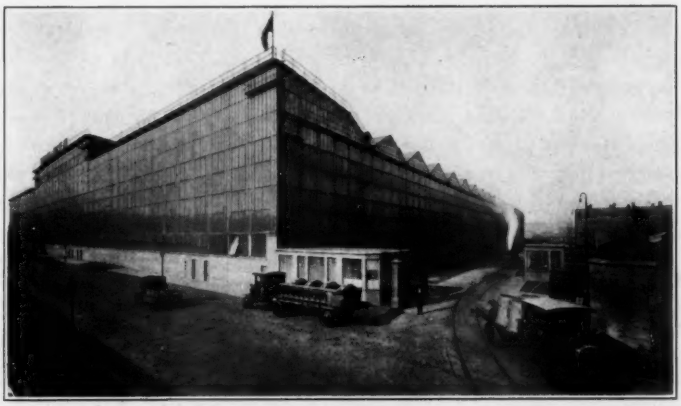

FIG. 11—CLYDE FOUNDRY OF HARLAND & WOLFF, COVAN, GLASGOW. THIS IS PROBABLY THE LARGEST FOUNDRY SHOP IN GREAT BRITAIN.

importance it has attained on the American continent, but their popularity is beginning to extend to the suburban villa.

TEXTILE ENGINEERING FOUNDRIES

55. It is highly probable that no country in the world possesses such an important group of foundries devoted to the production of textile-machinery castings as does Great Britain. The products of John Hetherington, Mather & Platt, and Platt Bros., are well known and appreciated the world over. In many lines, however, there is not too great a scope for the introduction of quantity production methods. Nevertheless, they possess a vast reserve of highly-skilled craftsmen, and their castings are a real credit to the foundry industry.

SHIPBUILDING

56. The shipbuilding section of the foundry industry assumes greater importance in Great Britain than in most countries, and the foundry of Harland & Wolff at Covan, Glasgow, has the largest foundry building in the country for this type of work. Like the textile-machinery foundries, they do not lend themselves to mass production methods. They do, however, excell in metallurgical control, and several have thought fit to install and work the Perlit and Emmel systems for making high-duty cast iron.

OTHER FOUNDRIES

57. The foundries catering to the railroads, the electrical engineering industry and agricultural implements, are of less importance in Great Britain than in the United States, as American foundries have to cater to the requirements of a continent, which Great Britain cannot equal even with its export trade. Since the inception of the regional electrification schemes, great progress has been made in the economic manufacture of distribution boxes and the like.

58. Up to now, the foundries have been reasonably successful in resisting the frequently ridiculous competition of welding. The British founders are rapidly awakening to the fact that, by cooperation with the designer and metallurgist, they can meet and overcome the competition offered by the welding trades. In Britain we refuse to accord to weldings the high-sounding title of "fabricated structures," as both castings and riveted jobs have equal claim to the copyright of this term.

JOBBING FOUNDRIES

59. While many jobbing foundries still operate on old-fashioned lines, it is safe to say that there is a general tendency to adopt scientific methods. Bad working conditions are not tolerated by the factory inspectors, while the services of numerous consulting and testing houses are regularly utilized by the majority.

60. In the country towns there still exist a number of tiny foundries which cast plough-shares of a type suitable for the local soil. Others make municipal castings such as gas lamps, manhole covers and the like, but their trade is gradually being diverted to more modern concerns employing molding machines and up-to-date equipment.

CONCLUSION

61. From this review, it will readily be realized that there is little community of interests between the attached and detached foundries, the shipbuilders and the rain-water goods manufacturers, and it is the work of the scientific institutes and technical press to form a link between such divergent interests. The work is difficult, but there are at the moment some grounds for belief that, in the not-too-distant future, an effective liaison will be created of such a character that the foundry trades will be converted to an industry truly nationally represented and appreciated.

Thermal Balances and Fuel Costs of Malleable Melting Furnaces*

By J. H. Hruska,† Berwyn, Ill.

Abstract

It has been shown by earlier attempts that the determination of heat balances for various melting units presents many desirable applications in the economical operation of the melting department of any modern malleable foundry. In order to be of still more useful value to the management, however, the correctly established heat balance for each melting furnace should be supplemented by such data taking into consideration the actual expenditures for the utilized fuel. For comparative purposes, fuel costs are best introduced into consideration per 1,000 or 1,000,000 B.t.u. With this in mind, the present paper is a report on systematic studies, endeavoring the correlation of strictly metallurgical heat balances of melting furnaces together with actual costs of the mentioned amounts of B.t.u. for the fuels used as heating media. By controlling certain items from reliable heat balances and by considering all possibilities as to prevailing costs of available fuels and equipment, frequently very substantial reductions in melting costs may be realized without affecting other important characteristics of the melting process, as for instance, relative speed of melting, quality of the produced iron, temperature of the melt, etc.

Introduction

1. When scrutinizing the presently known and utilized procedures of transferring solid metallic mixtures of a specific chemical composition into the molten state, the fundamental re-

*Presented through the technical committee of the American Association of Czechoslovak Engineers, Inc., Chicago.

†Metallurgical Engineer.

quirements relating especially to the needs of the malleable foundry may be considered from two points of view, as follows:

(a) The selected method must warrant a chemically controllable melting process.

(b) The heating, melting and overheating of the charged metals should be governed by the most favorable principles of sound economy.

Selection of a Melting Process

2. Combining both principles, the executive of any progressive malleable foundry will select such melting processes as will yield a chemically and metallurgically satisfactory melt at the lowest possible cost of transformation of ferrous matter from the solid to the liquid state.

3. Quite a number of excellent contributions, papers and lectures before the American Foundrymen's Association and other leading technical societies have added considerably to the theoretical and applied metallurgy of the most appropriate production of black-heart malleable iron. However, the foundry literature of today lacks very conspicuously more thorough discussions of the economical aspects of the utilized means for efficient melting in the foundry.

4. With this in mind, it is hoped that the following remarks may add to the splendid work of the A. F. A. Cost Committee, at least, to the technical side of its endeavor.

Importance of Low-Cost Melting

5. In the individual plant, the importance of low-cost melting may best be ascertained from the so-called "percentual analysis" of the cost sheet for the malleable melting department. As an example, Table 1 presents the actual cost summary for the production of one ton of hard iron, made in an acid-lined, electric-arc furnace.

6. The last column in this table shows clearly that the cost of actual melting is secondary only to the expenditures for the metallic charge. Therefore, any systematic effort to lower this particular item, without affecting the quality of the product, must be of a highly remunerative character to the plant management.

FUEL COSTS

7. The keen contemporary competition in the malleable iron trade necessitates, without doubt, the most careful consideration of the metallurgical characteristics and calorific efficiency of various fuels, as well as of the necessary heating equipment or melting unit, respectively.

8. For strictly comparative purposes, however, the original fuel costs per unit weight or unit volume should be figured so as to include all transportation, preparation, storage and delivery to the furnace. Furthermore, they should be based preferably on larger units of B.t.u.—from the cost of fuel per pound, cubic foot, gallon or kilowatt-hour, the cost per 1000 or even 1,000,000 B.t.u. may be obtained by simple mathematics. This is illustrated in Table 2.

9. It may readily be seen that Table 2 gives a summary of

Table 1

COST SUMMARY PER TON OF WHITE IRON (MADE IN ELECTRIC FURNACE)

Raw materials, etc.	Percent of metallic charge	Price per gross ton	Cost per ton	Amount per ton	Percent of items
Charge:					
Pig iron, Bessemer	38.4	$24.47	$ 9.40	.....	.....
Sprues, hard iron	40.6	15.00	6.09	.....	....
Bought malleable	14.5	17.84	2.59	.....	....
Steel scrap, own	6.2	14.50	0.90	.....	....
Pig and scrap	99.7	.....	$18.98	$18.98	57.4
Additions	0.3	.....	$ 0.17	$ 0.17	0.5
Gross metal	100.0	.....	$19.15	$19.15	57.9
Labor				$ 1.78	5.3
Power (at $0.0116/kwh—511 kwh per ton)				5.93	17.9
Electrodes (at $0.08/lb.—22.6 lbs. per ton)				1.81	5.4
Refractories, sand, etc				0.53	1.6
Cooling water				0.07	0 2
Maintenance				0.32	0.9
Supplies				0.12	0.4
Interest and depreciation				1.02	3.1
Miscellaneous losses in melting				0.73	2.2
Supervision and laboratory				1.68	5.1
Net production costs				$13.99	42.1
Total cost of 1 ton of hard iron at spout				$33.14	100.0

average costs for fuels used predominantly in the preparation of molten hard iron in the American malleable industry. Other items not being considered, very radical differences in fuel costs will be noted, which fact would indicate the advisability of development of coal- and coke-fired furnaces, *i.e.*, air furnaces and cupolas.

10. On the contrary, while economically important, melting costs are not exclusively governed by fuel costs, but are the derivative of additional and frequently more important items of the cost sheet.

Table 2

FUEL COSTS

Fuel No.	Type of fuel and cost unit	Calorific value, B. t. u.	Unit Cost: Per ton, in dollars	Unit Cost: In smaller quantities, in cents	Fuel Cost: Per 1,000 B. t. u., in cents	Fuel Cost: Per 1,000,000 B. t. u., in dollars
1	Electric energy, per kwh	3,413	....	1.53	0.448	4.48
2	City gas, illuminating, per cu. ft	568	....	68	0.120	1.198
3	Producer gas, per cu. ft	135	....	9.3	0.069	0.689
4	Natural gas, per cu. ft	1,080	....	55	0.055	0.545
5	Oil, per gal	142,100	....	5.8	0.041	0.407
6	Coke, foundry, per lb	13,610	9.20	0.42	0.031	0.308
7	Coal, pulverized, per lb	14,050	7.52	0.342	0.026	0.262
8	Coal, hand-fired, per lb	13,800	6.70	0.304	0.022	0.220

HEAT CONSUMPTION PER TON OF HARD IRON

11. Fuel costs and conversion costs per weight units such as one hundred pounds or one gross ton for the various melting furnaces represent figures which are always of importance for low operating expenses of a malleable foundry. In laying out the exact production costs, comparisons—within the plant or, eventually, with competitive enterprises—of the named values are unquestionably the most desirable information for future improvements of plant technique.

12. For this reason, most producers of malleable keep daily records of the exact amount of fuel consumed for each melt. Every month, when summing up the items pertaining to melting costs, the average fuel consumption usually is being reported in terms like pounds coal per ton, gallons of oil per ton or kilowatt-hours per ton.

13. While, obviously, some differences are experienced for the furnaces or heats of identical tonnage in the various plants, or even in the same plants, the total averages of fuel consumption generally are well comparable. However, when making comparisons between the amounts of B.t.u. required for the preparation of one ton of molten hard iron by means of the various processes, surprisingly large deviations will be observed for the corresponding methods of melting.

14. Thus, for instance, the production of one ton of hard iron in an air furnace of the almost conventional capacity of 25 tons may be accomplished by consuming between 8,000,000 to 14,000,000 B.t.u. On the other hand, in a 3 to 6-ton electric arc furnace only 1,500,000 to 2,100,000 B.t.u. are required to produce one ton of hard iron of identical chemical analysis and fluidity as compared with the air-furnace iron.

15. When computing the fuel consumptions for some of the applicable processes for making hard iron, and expressing the amount of fuel involved by its actual calorific value, *i.e.*, B.t.u per ton produced, the tabulation of heat consumption will be obtained, as given in Table 3.

16. In the fuel consumptions or B.t.u. values per ton given in Table 3, possible savings derived from utilization of waste heat have not been included. However, it is hoped that perhaps a more appropriate understanding would be given to all matters connected with fuel consumption and fuel economy if the consumed calorific energy were expressed in B.t.u. rather than in the better comprehended or more conventional terms.

17. This attitude has become especially desirable in the last few years, as the rapid advent of the electric arc furnace in the malleable industry has made comparisons with other processes necessary. This development brought about a terminology which very often represents quite a problem in itself of how to compare, for instance, consumptions like pounds of coal per 100 lbs. of iron *versus* kilowatt-hours per ton, and the like.

THERMAL EFFICIENCIES OF MELTING FURNACES

18. At present a truly informative survey of distribution or utilization of costly heat in melting departments of malleable foundries cannot be conducted without a thorough technical analy-

sis of the principal items entering into the well-known heat balances for metallurgical furnaces.

19. Perhaps it was an unfortunate coincidence that in the earlier days the apparently complex problem of efficiency or heat balance was mostly connected with the clarification of some highly scientific theory, instead of being of resourceful guidance in the selection of melting processes or in the reduction of conversion costs. The last few decades, however, have brought the properly determined heat balance or thermal efficiency into the proper light, which fact is unquestionably a very opportune one, at least for the present needs of the malleable foundries.

20. It would be far beyond the intended outline of the present paper to deal with the exact technicalities in carrying out the preliminary tests as well as with the methods of computing the observed, measured and calculated values. For convenient comparison, all mass and heat balances made in recent years and used in the present paper were reduced to a temperature of 60 degs. Fahr. and normal barometric conditions.

21. In all instances, the total actual in-put of heat was as-

Table 3

HEAT CONSUMPTION

Characteristics of furnace	Capacity	Fuel used	Calorific value of fuel, per pound	Fuel consumption per ton of iron	Heat consumption, B. t. u. per ton
Air furnace, hand-fired, cold furnace	25	Coal	13,790	973 4 lbs.	13,430,000
Air furnace, hand-fired, preheated furnace	25	Coal	14,060	671.5 lbs.	9,440,000
Air furnace, powdered coal, cold furnace	30	Coal	14,105	815 0 lbs.	11,696,000
Air furnace, powdered coal, preheated furnace	30	Coal	14,105	604.2 lbs.	8,526,000
Open-hearth furnace	25	Oil	15,820	351 9 lbs.	5,565,000
Cupola, 46-inch diameter	7 tons per hour	Coke	13,140	298.4 lbs.	3,922,000
Electric arc furnace, cold charge	6	Electricity	3,413 per kwh	528 6 kwh	1,804,000
Electric arc furnace, continuous	6	Electricity	3,413 per kwh	472.0 kwh	1,611,000

sumed to be 100 per cent, including the equivalent calorific value of the fuel (coal, coke, electric energy, etc.) together with the thermal energy produced by bath reactions and the heat content of the charged materials. The almost negligible influence of the air in each of the furnaces was determined from compositions of the furnace gases, representing averages of as many as eighteen complete chemical analyses, made during the heats under observation.

22. Fuels, charges, as well as the resulting hard iron, slag, gases, etc., were carefully weighed and measured so as to assure the reliability of the reported heat distribution. Almost any imaginable matter entering into the chemical or thermal reactions during melting has been duly considered so as to give a true picture of the efficiency of the presently known and commercially proven methods of producing hard iron.

23. Table 4 represents an average of many individual thermal balances, obtained exclusively on regular heats. Positively

Table 4

HEAT BALANCES (IN PER CENT)

Kind of furnace	Air Furnace: Hand fired	Air Furnace: Powdered coal	Open-hearth furnace	Cupola straight lined	Electric furnace
Capacity in tons	25	30	25	7.12 (per hr.)	6
Thermal Input:					
Fuel, combustion and own capacity	95.8	96.0	95.5	96.9	99.0
Exotherm. reactions	3.2	2.9	3.1	1.2	0.6
Air for combustion	0.8	1.0	1.3	1.7	0.1
Charge, own capacity	0.2	0.1	0.1	0.2	0.3
Total	100.0	100.0	100.0	100.0	100.0
Thermal Output:					
Gases and stack loss	67.1	68.6	26.7	12.5	(Not det.)
Reduction CO_2 to CO	....	....	....	26.6	....
Incomplete combustion	3.0	2.1	4.2	....	....
Loss through grates	1.9	....	....	....	....
Heat to checkers	....	....	26.9	....	....
Slag	0.5	0.8	1.2	4.0	2.1
Cooling water	....	....	....	....	4.2
Radiation and loss	18.2	19.0	26.4	21.1	38.8
Thermal capacity of molten white iron at approx. 2,900 degs. Fahr	9.3	9.5	14.6	35.8	54.9
Total	100.0	100.0	100.0	100.0	100.0

no extraordinary practice is being claimed for the heats or furnaces observed nor for the results thus obtained.

CONCLUSIONS

24. The modern operations pertaining to the manufacture of hard iron of definite chemistry demand not only a thorough knowledge of the exact behavior of various melting furnaces from a strictly metallurgical standpoint, but also the realization of certain economical principles governing the melting process utilized for that purpose.

25. Obviously, these principles must conform to sound judgment and the vision of those in charge, and should also take into consideration such factors as output of molten metal per hour, necessities for additional equipment, operations or labor, decrease of maintenance costs, etc. It is known from actual experience that the enthusiastic pursuance of B.t.u.'s by many an executive often brought about just the opposite results in the efficient management of the malleable melting department, by causing undue and costly difficulties in melting or pouring and thus increasing production costs beyond prohibitive limits.

26. In order to prove the futility of overemphasizing the importance of heating problems, a table has been compiled which

Table 5

FUEL COSTS PER TON OF IRON

Melting furnace	Heat consumed per ton of molten iron	Fuel cost per ton of iron	Remarks
	In B. t. u.	In dollars	
25-ton air furnace, hand-fired	13,430,000	2.96	Cold furnace
	9,440,000	2.08	Preheated furnace
30-ton air furnace, powdered coal	11,096,000	2.90	Cold furnace
	8,526,000	2.24	Preheated furnace
25-ton open-hearth furnace	5,565,000	2.26	Oil-fired
46-inch cupola	3,922,000	1.21	
6-ton electric furnace	1,804,000	8.09	Cold charge
	1,611,000	7.23	Continuous melt
	1,740,000	4.08	Own power plant

shows the net costs of fuels per ton for certain processes. The actual amount of B.t.u. (derived from some of the mentioned heat balances) being multiplied by the cost of 1,000,000 B.t.u. of various fuels, the resulting differences are not as pronounced as is usually anticipated. This is shown in Table 5.

APPENDIX

27. In order to illustrate the general outline of the many thermal balances secured for the previously mentioned data, one example for each of the various groups is presented in the appendix herewith. However, only such values are included as would represent the general practice or manufacturing routine for the heats under consideration. Averages of the percentual balances obtained from series of determinations on the identical furnaces, but for various heats, are given by the values in Table 4.

A—Air Furnace, Hand-Fired

FURNACE:

Nominal capacity	25 tons
Fuel	bituminous coal
Heats on hearth	12th
Condition of furnace	Cold (Monday heat)

RECORD OF HEAT:

Firing started	11:24 P. M.
First slagging, started	3:55 A. M.
First slagging, finished	4:10
Second slagging, started	5:21
Second slagging, finished	5:33
Superheating started	6:15
Tapping started	8:20
Pouring finished	9:08
Tapping temperature	2960°F.

CHARGE:

Weight of ferrous charge	40,430 lbs.
Composition:	
Pig iron	55.8%
Sprues	29.2%
Malleable scrap	12.0%
Steel scrap	3.0%
Total	100.0%

SLAG:

Total weight of slag	2,505 lbs.
Slag per ton of iron	136.5 lbs.
Total heat in slag	319,950 cal.
Heat in slag per ton of iron	17,400 cal.

CHEMISTRY:

Analysis of white iron:

% TC	2.62
% Si	0.99
% Mn	0.31
% P	0.118
% S	0.041

Loss of chemical elements:

% C	0.73
% Si	0.25
% Mn	0.20

FUEL:

Total weight of coal utilized	18,680 lbs.
Lbs. of coal per 100-lb. charge	46.2
Total time of firing	9.74 hrs.
Firing under blast, %	35.9
Firing without blast, %	64.1

Grade of coal:

Size	2 to 3 in.
Ash, %	2.83
Water, %	2.11
B. t. u. per lb.	14,120
Cal. per kg.	7,828

Gas Analysis:

% CO_2	13.6
% CO	1.3
% O_2	2.8
% remainder	82.3
Total heat from coal	66,414,000 cal.
Heat from coal per ton of iron	3,618,000 cal.
Weight of ash, through grates	945 lbs.
Thermal loss in ash, total	1,435,000 cal.
Thermal loss in ash, per ton of iron	78,200 cal.

THERMAL INPUT:	Cal.	%
Fuel, combustion and own capacity	3,618,000	97.2
Exothermic reactions	82,000	2.2
Air through furnace	19,100	0.5
Charge, own capacity	1,700	0.1
Total	3,720,800	100.0

THERMAL OUTPUT:	Cal.	%
Heat in white iron	281,000	7.6
Slag	17,400	0.5
Incomplete combustion	189,950	5.1
Flue gases and stack losses	2,589,600	69.6
Loss through grates	78,200	2.1
Radiation and loss	564,650	15.1
Total	3,720,800	100.0
	(14,760,000 B. t. u.)	

B—Air Furnace, Heated with Pulverized Coal

FURNACE:	
Nominal capacity	30 tons
Kind of fuel	powdered coal
Heat on hearth	16th
Condition of furnace	cold
RECORD OF HEAT:	
Duration of heat, excl. pouring	8.50 hrs.
Pouring period	0.833 hrs.
Tapping temperature	2925°F.
CHARGE:	
Weight of ferrous charge	59,600 lbs.
Composition:	
Pig iron	58.1%
Sprue	20.4%
Malleable scrap	9.9%
Spill and wash	11.6%
Total	100.0%
SLAG:	
Total weight of slag	2,610 lbs.
Total heat in slag	433,000 cal.
Heat in slag per ton of iron	16,000 cal.
CHEMISTRY:	
Analysis of hard iron:	
% TC	2.42
% Si	0.89
% Mn	0.29
% P	0.136
% S	0.048
Loss of chemical elements:	
% C	0.51
% Si	0.33
% Mn	0.26
FUEL:	
Total weight of coal utilized	17,340 lbs.
Lbs. of coal per 100 lbs. iron	29.1
Grade of coal:	
Ash, %	2.85
Sulphur, %	0.62
B. t. u. per lb.	13,980
Cal. per kg.	7,754
Gas Analysis:	
% CO_2	13.4
% CO	1.3
% O_2	3.7
% remainder	81.6

Screen Test:	
100 mesh	98.9%
240 mesh	83.0%
Total heat from coal	60,998,000 cal.
Heat from coal per ton of iron	2,248,000 cal.

THERMAL INPUT:	Cal.	%
Fuel, combustion and own capacity	2,248,000	96.1
Exothermic reactions	77,800	3.3
Air through furnace	12,500	0.5
Charge, own capacity	1,700	0.1
Total	2,340,000	100.0

THERMAL OUTPUT:	Cal.	%
Heat in white iron	268,000	11.4
Slag	16,000	0.7
Incomplete combustion	91,000	3.9
Flue gases and stack losses	1,568,000	67.0
Radiation and loss	397,000	17.0
Total	2,340,000	100.0
	(9,280,000 B. t. u.)	

C—Open Hearth Furnace, Acid-Lined

FURNACE:	
Nominal capacity	25 tons
Kind of fuel	Fuel oil
Heat on hearth	52nd
RECORD OF HEAT:	
Duration of heat	6.467 hrs.
Tapping temperature	2945°F.
CHARGE:	
Total weight of ferrous charge (21.1 tons)	46,500 lbs.
Composition:	
Pig iron	47.0%
Sprue	36.1%
Malleable scrap	11.1%
Steel scrap	5.8%
SLAG:	
Total weight of slag	3,160 lbs.
Slag per ton of iron	149.5 lbs.
Total heat in slag	515,000 cal.
Heat in slag per ton of iron	24,430 cal.
CHEMISTRY:	
Loss of chemical elements:	
% C	0.68
% Si	0.32
% Mn	0.42

FUEL:

Consumption of fuel oil per ton of iron	48.0 gal.
Calorific value, B. t. u. per gal.	142,100
Calorific value, cal. per gal.	35,850
Heat from oil per ton of iron	1,720,800 cal.

THERMAL INPUT:	Cal.	%
Fuel, combustion	1,720,800	94.1
Exothermic reactions	87,600	4.7
Air through furnace	20,400	1.1
Charge, own capacity	1,700	0.1
Total	1,830,500	100.0

THERMAL OUTPUT:	Cal.	%
Heat in white iron	270,000	14.7
Slag	24,400	1.3
Incomplete combustion	78,000	4.3
Gases and stack losses	481,100	26.3
Heat to checkers (gain)	493,000	27.0
Radiation and losses	484,000	26.4
Total	1,830,500	100.0
	(7,260,000 B. t. u.)	

D—Cupola

FURNACE:

Nominal capacity, per hr	7 tons
Diam. of lining (straight)	44 in.
Condition of furnace	cold
No. of heats on lining	6

RECORD OF HEAT:

Fire lighted	8:03 A. M.
Blow out (2 min.)	9:11
Blast on	9:50
Tapping started	9:55
Last iron	11:24
Duration of heat (1 hr. 31 min.)	1.518 hrs.
Hourly output	7.17 tons
Average blast pressure	10.9 oz.
Temperature of metal at spout	2990°F.

CHARGE:

Total weight of ferrous charge (10.9 tons)	23,980 lbs.
Iron and alloys per charge	1,022 lbs.
Mixture per charge:	
Steel	300 lbs.
Sprue	700 lbs.
Ferrosilicon	7 lbs.
Spiegeleisen	15 lbs.
No. of charges	23.4

SLAG:

Total weight of slag	1,940 lbs.
Slag per ton of iron	178 lbs.
Heat in slag per ton of iron	66,900 cal.

FLUX:

Weight of each charge of flux	20 lbs.
Total flux charged	460 lbs.

FUEL:

Coke on bed (about 38 in.)	1,190 lbs.
Coke per charge	140 lbs.
Number of coke charges	23
Total coke in cupola	4,410 lbs.
Return after dropping bottom	1,050 lbs.
Net consumption of coke	3,360 lbs.
Grade of coke:	
% C	86.14
% Ash	11.37
% S	0.78
B. t. u. per lb.	13,050
Cal. per kg.	7,240
Heat from coke per ton of iron	1,022,400 cal.

CHEMISTRY:

Loss of chemical elements:	
% Si	0.36
% Mn	0.46

THERMAL INPUT:	Cal.	%
Fuel, combustion and own capacity	1,022,400	96.0
Exothermic reactions	36,100	3.3
Air through furnace	6,300	0.6
Charge, own capacity	1,700	0.1
Total	1,066,500	100.0

THERMAL OUTPUT:	Cal.	%
Heat in white iron	284,000	26.6
Slag	66,900	6.2
Reduction of CO_2 to CO	313,200	29.4
Gases and stack losses	153,400	14.4
Radiation and losses	249,000	23.4
Total	1,066,500	100.0
	(4,230,000 B. t. u.)	

E—Electric Arc Furnace

FURNACE:

Nominal capacity	6 tons
Diameter of electrodes	16 in.
Lining of furnace	acid
Charge	cold

RECORD OF HEAT:

Charging commenced	10:10 A.M.
Current on	10:43
All molten	2:08 P.M.
Tapped	2:54
Duration of heat (4 hrs., 11 min.)	4.1835 hrs.
Temperature of metal at spout	2920° F.

CHARGE:

Total weight of ferrous charge (6.41 tons)	14,102 lbs.
Total heat in molten charge	1,748,650 cal.
Heat in 1 ton of molten iron	272,800 cal.

SLAG:

Total weight of (acid) slag	655 lbs.
Heat in slag per ton of iron	23,600 cal.

COOLING WATER:

Roof Rings:

Water used per hour	7,130 lbs.
Average increase in temperature	5.5° C.
Heat consumed by water	74,550 cal.
Heat per ton of iron	11,650 cal.

Transformer:

Water used per hour	7,130 lbs.
Average increase in temperature	2.4° C.
Heat consumed by water	32,500 cal.
Heat per ton of iron	5,070 cal.

THERMAL ENERGY:

Total consumption of kw.-h. per ton of iron	543.0
Thermal equivalent of 1 kw.-h	860 cal.
Thermal equivalent of 543 kw.-h	466,980 cal.

THERMAL INPUT:	Cal.	%
Electric energy equivalent to	466,980	98.9
Exothermic reactions	2,600	0.6
Air through furnace	700	0.1
Charge, own capacity	1,715	0.4
Total	471,995	100.0

THERMAL OUTPUT:	Cal.	%
Heat in white iron	272,800	57.7
Slag	23,600	5.0
Cooling water, rings	11,650	2.5
Cooling water, transformer	5,070	1.1
Radiation and other losses	158,875	33.7
Total	471,995	100.0
	(1,871,000 B. t. u.)	

DISCUSSION

J. R. ALLAN:[1] Under Table 5, "Cost of Fuel per Ton of Iron," does the powdered coal cost include the cost of pulverizing?

J. H. HRUSKA: Yes, because in all cases I mention in the paper that all the costs have been included in the tables, meaning, in other words, the cost of fuel at the furnace—entering the furnace.

H. W. HIGHRITER:[2] It would seem to me that the subject of fuel costs, as listed in Table 2, is so largely an individual proposition, depending upon locality, that it is unfortunate the localities involved are not indicated.

J. H. HRUSKA: I could not go into the details for the reasons mentioned in my conclusive notes.

H. W. HIGHRITER: I know a number of places where, due to geographical location, oil is a much cheaper fuel to use than coal, and others where the normally high cost of electricity is considerably reduced by local conditions.

Under Table 3, which considers the heat consumption and fuel consumption, it would seem to me that the value for fuel consumption of the air furnace—hand fired, with cold furnace—of 973.4 lbs. per ton iron, is somewhat high for a 25-ton heat. One would anticipate that, with a 25-ton heat, even in a cold furnace, one might have a coal consumption ranging from 750 lbs. down to less than 700 lbs.

J. H. HRUSKA: Yes, that is true. This was a Monday morning heat. Perhaps that fact should have been mentioned in the paper.

H. W. HIGHRITER: The same applies to powdered-coal furnaces. Often 25-ton heats are melted with less than 600 lbs. coal per ton iron in a cold furnace. Of course, the second heat, with a hot furnace, would be still lower.

J. H. HRUSKA: I did not intend to criticize the practice, but I would like to show in the table, in tabular form and in the form of heat balances, how those things could be determined. That is the main purpose of the paper, and not to criticize whether this is good practice or not.

W. R. BEAN:[3] This paper is of considerable interest to those who study the melting methods in malleable foundries, and in particular, the heat balance record is of value. I do not know that there is anything really to be gained by drawing comparisons between the hand-fired and the pulverized-coal-fired figures as presented, because I know that the conditions were abnormal and unusual for the original records.

Take, for instance, the difference in the cost of low-priced coal and the coal used in hand firing. I know that the coal for both purposes came from the same mine, and that the coal used for pulverized coal firing cost more per ton delivered than the coal used for hand firing. Therefore, at the very start, those particular figures should not be considered as carry-

[1] Industrial Engineer, International Harvester Co., Chicago.
[2] Shop Engineer, Malleable Iron Research Institute, Cleveland.
[3] President, Grindle Fuel Equipment Co., Harvey, Ill.

ing any meaning with regard to what normal accomplishment is with pulverized coal firing as compared with hand firing.

The general difference in the cost of the coal before pulverization will run around 75 cents a ton. It runs as low as 60 cents a ton in some cases, and in some communities it runs as high as $1.25 or $1.50 a ton. Anyone who desires to work up a heat balance or a comparison using the basic idea as expressed will have to consider individual conditions.

In general, I believe it can be stated as a fact that today the use of the electric-arc furnace in the malleable industry is declining rather than increasing. The number of tons melted in that manner today is less than at any time during the past ten or fifteen years.

The principal reasons for this lie, probably, in the cost of operation of the electric furnace, when all factors are taken into consideration. There are few communities in which the electric furnace can be used economically in comparison with other methods of melting.

At present the trend seems to be to melt in the cupola and to duplex with the air furnace rather than with the electric furnace, under certain conditions.

J. H. HRUSKA: I do not think I will have to answer the statements made by Mr. Bean, because they are a little outside the scope and intention of my paper. I believe the general discussion as presented by Mr. Bean is correct.

As a matter of fact, I think about forty thermal balances have been made of which the figures in my paper represent an average, and everyone who has ever made or tried to make a correct thermal balance in any kind of furnace probably will appreciate the work involved in the figures.

L. J. KELLEY:[4] We have realized the heat losses in open-hearth furnaces, so we rebuilt one last year and I would like to check with some of Mr. Hruska's figures. We have a 45-ton furnace, and in operating 25 to 30 tons in our furnace, from charge to tap, we will average about 30 gallons per ton iron, of 14 to 20 gravity oil. Our furnace is all insulated wherever possible. Thus, in a 45-ton heat, operating from charge to tap, we average 28 gallons per ton iron.

In the 25-ton furnace mentioned by the author, is this 48 gallons shown there, for 24-hour operation?

J. H. HRUSKA: No, it is for an individual heat, especially on Monday. I tried to put all the comparisons on a more or less uniform schedule. The 48 gallons represents a Monday morning first heat.

L. J. KELLEY: That is pretty high, is it not? Our furnace, running two-thirds its capacity, averages 30 gallons per ton.

J. H. HRUSKA: Yes, I realize that it is high, but I consider your average to be good practice.

L. J. KELLEY: Do you know what gravity oil is used?

J. H. HRUSKA: I could not say, because all I had on hand was the B.t.u. value of the oil per gallon—142,100, as shown in Table 2. The 48 gallons is based on the metal cast.

[4] Superintendent, Fort Pitt Malleable Iron Co., Pittsburgh.

Report of Nonferrous Committee on Recommended Practices

At a meeting of the A. F. A. Nonferrous Division committees, held during February, 1930, a Committee on Recommended Practices was authorized and instructed to formulate recommended practices relating to the more standard nonferrous alloys. This committee then selected three alloys to be covered in its initial project. These alloys are:

(1) Copper 85, tin 5, lead 5, zinc 5.

(2) Copper 80, tin 10, zinc 10.

(3) Manganese bronze (A. S. T. M. Specification B-54-27).

The recommended practices which were developed were reviewed by the divisional committees and approved for printing as tentative, subject to criticism and revision at the 1931 annual meeting. The committee desires especially to have suggestions as to additional data to be listed and checking of the practices as outlined. It is to be understood that these recommendations are issued essentially as guides for those foundrymen who are not familiar with the production of these alloys.

Tentative Recommended Practice for the Alloy Copper 85, Tin 5, Lead 5, Zinc 5

PHYSICAL PROPERTIES FOR SAND CASTING

Ultimate tensile strength (minimum to average practice) per sq. in.	26,000-32,000 lbs.
Proportional limit in tension (approximately) per sq. in.	8,000-10,000 lbs.
Yield point in tension (minimum to average practice) per sq. in.	12,000-15,000 lbs.
Elongation in tension (in 2 in.) usual range	15-25%
Compression of 0.001 in. (on cylinder 1/2 in. square cross-section and 1 in. high)—approx.	10,000-12,000 lbs.
Compression of 0.1 in. (on cylinder 1/2 in. square cross-section and 1 in. high)—approx.	32,000 lbs.
Brinell hardness number	48-58
Pattern maker's shrinkage (per ft.)	3/16 in.
Specific gravity	8.7
Weight per cubic inch	0.314 lb.
Resistance to impact (Izod test), ft. lbs., approx.	8

RECOMMENDED PRACTICE

Development and Field of Use.

1. This alloy formerly was known as ounce metal, owing to the ratio of copper to any one of the other three elements being approximately 16 to 1. It has many variations in its composition, due to the fact that it is a widely used alloy. It is generally recognized as a high-grade nonferrous alloy, giving daily satisfaction in the manufacture of many pressure castings, certain bearings and for all work where good color and ease in machining are important factors.

Chemical Control.

2. The chemical composition should be known and controlled at all times, as variations may be the cause of unsatisfactory results in the castings. By varying the tin, lead, zinc and phosphorus, it is possible to change the alloy's melting point, freezing range, shrinkage, pouring temperature, fluidity and other physical properties.

Sand.

3. Sand of about A. F. A. No. 1 or No. 2 grain size, D to F clay content or grain fineness about 140, and clay content 5 to 20 per cent, is suggested for this alloy, as most castings made of it must be smooth and clean. The sand must have such bond that it will not scab but will lift well. It should be such that lettering and other detail will be sharp. Sometimes it may be advisable to spray the mold with molasses water and dry to obtain the best results.

Cores.

4. Fine silica sand and a good grade of core oil are suggested for this alloy. Painting the core with graphite may help in making castings smoother on the inside. Additions of sandblast dust or silica flour to the core-sand mix often will increase its ability to stand while green and to make a much stronger dry core.

5. It is very important to have very strong, well-vented cores, as many of the castings are intricate, have thin walls and much pressure is placed on the core when the metal is being poured. However, the cores must not be hard enough to cause castings cracks or difficulty in shaking out.

Gating and Heading.

6. Gating and heading of castings made of this alloy is very important. A study of each particular class of castings should be made before deciding what type of gate is to be used.

(a) Castings such as heavy-flanged valve bodies must have feed heads for the flanges, and a skimmer gate with a blind head is suggested.

(b) For castings such as index plates and light uniform castings, where speed of pouring is necessary to run them, a choke gate is used.

(c) For castings of very non-uniform section where speed of pouring is necessary to run them, the use of choke gates and feeding heads, set on the heavy parts to take care of the shrinkage, is suggested.

(d) Castings of the small uniform variety may best be gated by a simple brass or bronze gate.

Cleaning Castings.

7. Gates and heads on castings made of this alloy are removed by various methods such as the band saw, sprue cutter, friction wheel, or breaking off while hot. They are cleaned by blasting. If rumbled, they are easy to mar.

Chilling.

8. Simple castings can be made in chills successfully and have a very dense grain. However, many of the castings made of this alloy are very intricate and not well adapted to this process.

Melting.

9. General good furnace practice is necessary for this alloy. A pouring range between 1950 and 2300 degs. Fahr., according to the thickness of the castings, is suggested, keeping in mind that phosphorus and other elements have an effect on the fluidity. Zinc, tin and lead must also be added for burn-out in accordance with furnace practice.

Impurities and Their Effects on Alloy.

(a) *Phosphorus* is added as a deoxidizer and should be kept in close control, as it has a very decided effect on this alloy. The phosphorus is best added to the pot just before pouring, and only enough should be added to reduce the oxides present. Phosphorus has a tendency to make the metal more fluid, which increases its ability to penetrate any cores present and also has a tendency to make dirty castings.

(b) *Iron* is an impurity in the alloy. It is found in solution or in the free state. In both cases it is detrimental and should be kept as low as possible. When in the free state it makes hard spots, and when in solution it increases internal shrinkage and discolors the alloy.

(c) *Aluminum* is an extremely dangerous impurity, and even a few hundredths per cent is likely to ruin the alloy, making it very unsound. Aluminum apparently alters the crystalline characteristics of the alloy very markedly, even very small amounts sometimes causing lead sweat.

(d) *Antimony* is an impurity that alloys well with the

rest of the mixture and is very hard to eliminate, as it does not burn out very easily. Its effect on this alloy is widely discussed by nonferrous foundrymen and metallurgists, but good castings can be made when this element is kept within the limit of 0.25 per cent set by the A. S. T. M. specification.

(e) *Nickel* is an impurity which is not harmful to this alloy. Nickel up to 0.75 per cent apparently is not detrimental. In larger amounts the alloy is not a regular 85-5-5-5, but falls into the special alloy class.

(f) *Sulphur* is an impurity in this alloy. There is some question as to the amount necessary to produce distinctly harmful results. Recommended practice relative to this impurity awaits results from work now in process. Up to 0.08 per cent is not considered harmful.

(g) *Silicon* is an impurity in this alloy, and it is generally conceded that it is very harmful in the alloy as the silicon reacts with the lead and gives very drossy and dirty castings. Even a few hundredths of one per cent should be avoided.

Revision.

10. The Committee on Recommended Practice expects from time to time to make additions, corrections and revisions as increased information becomes available.

(*Continued on next page*)

Tentative Recommended Practice for the Alloy of Manganese Bronze*

PHYSICAL PROPERTIES FOR SAND CASTINGS

Ultimate tensile strength per sq. in.	65,000 lbs. min.
Proportional limit in tension per sq. in.	16,000-20,000 lbs.
Yield point in tensile per sq. in.	30,000-40,000 lbs.
Elongation in tension (in 2 in.)	20-35%
Reduction in area	15-30%
Compression of 0.001 in. (on cylinder 1/2 in. square cross-section, 1 in. high) at	22,000-26,000 lbs.
Compression of 0.1 in. (on cylinder 1/2 in. square cross-section, 1 in. high) at	85,000-90,000 lbs.
Brinell hardness number	109-119
Pattern maker's shrinkage (per ft.)	7/32 in.
Specific gravity	8.4
Weight per cubic in.	0.303 lb.
Resistance to impact (Izod test), ft. lbs.	15-24

RECOMMENDED PRACTICE

Development and Field of Use.

1. This alloy was developed by P. M. Parsons in 1876. Strictly speaking, manganese bronze is a high-tensile complex brass and owes its remarkable properties to the incorporation of one or more of the elements aluminum, iron, manganese and tin in the basic brass mixture. It finds use where a high-strength, ductile, corrosion-resistant, non-magnetic metal is required; hence, it is widely used in the electrical industry and in marine and automotive work.

Chemical Control.

2. Close chemical control is necessary to insure the desirable mechanical properties in the casting. The strength and ductility are markedly sensitive to slight variations in the constituent elements, particularly zinc and aluminum, which also influence the shrinkage.

* American Society for Testing Materials Specification B-54-27. (Copper, 55 to 60 per cent; zinc, 38 to 42; tin, 1.50 maximum; iron, 2 maximum; manganese, 3.50 maximum; aluminum, 1.50 maximum; lead, 0.4 maximum.)

Sand.

3. Considerable latitude is permitted in the grain size of the sand used on this alloy. The film of alumina carried on the surface of manganese bronze gives a fair finish even in coarse sand. A sand is recommended having the characteristics of No. 2 Albany, with a moisture content ranging from 6 to 7.5 per cent. Skin-drying or other surface treatments to secure fine finish are not ordinarily practiced on this alloy.

Cores.

4. The high strength of the alloy permits the use of strong cores without danger of developing excessive strains in the casting while hot. The use of silica sand with a good grade of core oil is suggested. Blacking with graphite is practiced on most work to assist in the removal of cores from castings, the finish, however, being good on untreated cores. Due to the high shrinkage, chills are frequently imbedded in dry-sand cores on work of irregular section to prevent local shrinkages. The regular practice as to venting and reenforcing apply to this alloy.

Molding Precautions.

5. Manganese bronze is characterized by very high shrinkage and a tendency to form dross when agitated. Castings should be designed with as uniform cross-section as possible. Where this is impractical, generous fillets should be provided at section junctions and the heavier sections either chilled or well fed. The drossing tendency makes necessary special precautions in the gating of this alloy, in order to prevent dross inclusions in the casting generated by turbulence at the entry. Clean castings are successfully made by filling the mold by simple displacement, as in bottom pouring, or any other method whereby the velocity of the stream from the gate is reduced to a minimum. Choke gates, strainer cores, and pouring basins are successfully used to prevent entry of dross from the ladle.

Melting.

6. This alloy is melted in all the common types of furnaces. Due to the low boiling point of zinc, close control of the melting equipment is necessary to maintain uniformity of product. Fluxes

are useful on all forms of melting of this alloy to retard the vaporization of this element. Soda ash in particular is recommended.

7. The superheat required on this alloy is very low; a pouring temperature of 1832 to 1922 degs. Fahr. will suffice for all work. Additions, to compensate for selective melting losses, are made at the end of the melt. No deoxidizer is required, the alloy being thoroughly deoxidized by its own constituents.

Impurities.

(a) *Lead* is the chief impurity found in manganese bronze. In large castings, or in castings that are likely to be highly stressed, it is recommended that a maximum of 0.20 per cent be permissible. There is no question but that lead has a deleterious effect on mechanical properties and shock resistance in particular, an effect which may be greatly exaggerated by segregation of the lead in large castings. For castings unlikely to meet severe stresses, an upper limit of 0.5 per cent lead is not excessive. There is a possibility of buying extra high-grade zinc which carries practically no lead and which, if used, will produce a manganese bronze with such a low lead content as to improve materially the elongation and also some other characteristics of the alloy.

(b) Although *Tin* has been regularly used as a constituent of this alloy from its inception, there is evidence now to show that it may exercise an evil effect if carried to a slight excess. Some investigators suggest dispensing with it altogether, and, inasmuch as the lately developed super-high-tensile brasses contain no tin, it would seem advisable in most cases to hold it within low limits—0.50 to 0.75 per cent. However, in some cases a tin content up to 1.25 per cent is not only permissible but desirable, to increase the rigidity of the alloy and consequently influence the yield point, and is beneficial for a certain class of castings.

Revisions.

8. The Committee on Recommended Practive expects to make additions, corrections and revisions from time to time as the increased information becomes available.

Tentative Recommended Practice for the Alloy 80 Copper, 10 Tin, 10 Lead

PHYSICAL PROPERTIES FOR SAND CASTINGS

Ultimate tensile strength per sq. in.	26,000-33,000 lbs.
Proportional limit in tension per sq. in.	9,500-11,500 lbs.
Yield point in tension per sq. in.	18,500-20,000 lbs.
Elongation in tension (in 2 in.)	6-8%
Reduction in area	5.6-7.4%
Compression of 0.001 in. (on cylinder 1/2 in. square cross-section and 1 in. high) at	13,500-15,000 lbs.
Compression of 0.1 in (on cylinder 1/2 in. square cross-section and 1 in. high) at	45,000-47,000 lbs.
Compression of 0.27 in. to 0.30 in. (on cylinder 1/2 in. square cross-section and 1 in. high) at.	100,000 lbs.
Brinell hardness number	61-70
Pattern maker's shrinkage (per ft.)	3/16 in.
Specific gravity	8.9
Weight per cubic in.	0.322 lbs.
Resistance to impact (Izod test), ft. lbs.	3-8

RECOMMENDED PRACTICE

Development and Field of Use.

1. This alloy has long been considered a very good standard bearing metal. It is an excellent wearing material under conditions of high speed, heavy pressure, shock and vibration. Its resistance to corrosion is good as compared to most of the other alloys not especially designed to meet this requirement.

Chemical Control.

2. The chemical composition of the metal intended for use should be known, as the presence of elements other than copper, tin and lead in this alloy changes its melting point, freezing range, shrinkage, physical properties and pouring temperature. For instance, the tensile strength can be made to vary from 22,000 lbs. per sq. in. to 34,000 lbs. per sq. in., the elongation from 8 to 14 per cent, and the hardness from 45 to 65 Brinell (500 kg.), as the result of different ingredients or impurities being present.

Sand.

3. Sand for this alloy will give best results when sand having the characteristic of about No. 0 to No. 1 Albany grade is used for the lighter-sectioned castings, and when No. 4 to No. 6 with a graphite coating is used for the heavier-sectioned castings. The coarse grade of sand will help to eliminate cutting and scabbing.

Cores.

4. Cores for this alloy should be made of a fine silica sand and painted or dipped in graphite paint as this alloy has a great ability to penetrate dried sand.

Gating and Heading.

5. Simple brass or bronze gating can be used for this alloy, except that some kind of a skimmer should be used in the gate to hold back the phosphorus slag, which is very common to this type of alloy.

6. Heading of castings made of this alloy is controlled by the phosphorus content and, where there is sufficient phosphorus present, the elevated gate will serve as the head; but where the phosphorus content is low and the zinc is high, a blind head is preferred.

Cleaning Castings.

7. Gates and heads can be nicked and broken off. The castings can best be cleaned by the sandblast rumbling method.

Chilling.

8. This alloy is one of the bronze alloys that permits improvement easily by the chilling process. Chilling gives a very fine grain structure and tends to increase the physical qualities for the better, with the exception of ductility.

Melting.

9. Experience shows that the elements other than copper, tin and lead have an effect on the melting of this alloy both as to melting point and the quality of the resultant casting. Addi-

tions of phosphorus, tin and lead must be made for the burn-out, which is determined only by practice for each type of melting.

10. Pouring temperature varies indirectly with the amount of phosphorus present and the thickness of sections of the castings. To illustrate the relation of pouring temperature and phosphorus content, the data below are given:

Phosphorus.	Pouring temperature.	
Trace to 0.02	1900-2050°F.	Phosphorus used as a deoxidizer.
0.10-0.20	1840-1900°F.	Phosphorus used as a deoxidizer and part of alloy.
0.50-1.00	1500-1680°F.	Phosphorus used as one of the metals in alloy.

Impurities.

11. Impurities or ingredients other than the copper, tin and lead, and their effects on this alloy, are as follows:

(a) *Zinc* is an impurity and increases grain size and shrinkage, and lowers the physical qualities, but does not make the alloy unfit for all purposes.

(b) *Phosphorus* is not an impurity but is used for two purposes, (1) as a deoxidizer, and (2) as one of the component parts of the alloy. As a deoxidizer it is used to reduce any oxides present to their metallic state. As an ingredient it increases the hardness, tensile strength and ductility, and decreases its shrinkage, cooling range and melting point. High phosphorus content also makes the alloy more difficult to handle in the foundry.

(c) *Sulphur* is an impurity but is sometimes used to hold lead in solution. It is generally conceded that it is better out than in, as it creates a gas that is hard to eliminate and also forms sulphides which increase the hardness.

(d) *Iron* is an impurity in this alloy and is found both in solution and in the free state. In both cases it is detrimental to the alloy and should be kept as low as possible. It makes hard spots, increasing internal shrinkage and discolors the alloy.

(e) *Antimony* is an impurity. It alloys well with the rest of the mix and is very hard to get rid of, as it does not burn out very easily. It acts on the alloy very similarly to the action of zinc, giving increased grain size and affecting the physical qualities.

(f) *Aluminum* is an extremely dangerous impurity and even a few hundredths per cent is likely to ruin the alloy, making it very unsound. Aluminum apparently alters the crystalline characteristics of the alloy very markedly, even very small amounts sometimes causing lead sweat.

(g) *Silicon* is an impurity that should be kept in the class with aluminum, as it does not help the alloy but shows signs of making trouble.

(h) *Nickel* is not an impurity but is added for its ability to hold the lead and to increase its density, which naturally increases its other physical qualities.

Reports of Gray Iron Committees on Recommended Practices

A—Operation of a 54-Inch Cupola
B—Calculation of Cupola Mixtures
C—Analyses for Classes of Castings

Early in 1930 the Committee on Gray Iron Castings of the A. F. A. Gray Iron Division authorized the formation of three sub-committees to formulate recommended practices for the guidance of foundrymen. These three sub-committees have since presented reports on (1) 54-inch cupola operation, (2) calculation of cupola mixtures and (3) analyses for various classes of castings. These three reports are presented herewith in tentative form for discussion and criticism. Following the 1931 annual meeting of the Association, the sub-committees will revise their reports and again present them at the 1932 annual meeting, for adoption at that time as recommended practices.

A—Recommendations for Operation of a 54-Inch Cupola

I—Lining

(A) For lining up a new cupola or relining an old one, a good grade of cupola block of proper dimensions should be used. The block should be laid up with close joints and filled between with a fireclay mixture. Various mixtures[1] are used.

(B) The shape of lining depends on practice and may be classified under two types, as follows:

[1] Some typical mixtures are as follows: (1) One part fireclay, one part molding sand, one part sharp core sand; (2) one part blue clay, one part finely ground firebrick, two parts fire sand or heavy molding sand; (3) one part fireclay, two parts molding sand.

(1) Straight side; that is, straight from bottom doors to charging door.

(2) Boshed; that is, a 3 to 6 inch projection at top of tuyeres and tapering off to the straight side just above melting zone.

(C) After each heat, chip out badly burned brick and patch with new brick, maintaining the original outlines as closely as possible.

(D) A new breast brick or tap hole should be used if previous one has become too large for the desired flow of molten metal from the cupola.

The tap hole should be about 1 inch in diameter at the shell for intermittent tapping and should not be over 2 or 3 inches in length. For continuous operation the size should be adjusted to the melting rate. Its location is just at the level of the sand bottom.

(E) The slag hole should be located from 2 to 4 inches below bottom of tuyeres. Its size depends on thickness of lining and on size of cupola, usually from 1 to 2 inches either round or square.

II—TUYERES

The area of the tuyeres should be approximately one-third of the area of the cupola taken at the tuyeres. The height of tuyeres should be from 10 to 20 inches above the center of sand bottom, depending on amount of iron required at one tap. The tuyeres should be as nearly continuous as possible with a vertical opening 3 to 5 inches in height. For ordinary conditions, use only one row of tuyeres.

III—BOTTOM

(A) The bottom doors should be securely propped and rigid to eliminate possible cracking of sand bottom causing run out.

(B) The bottom sand should be carefully rammed and slope from all directions toward the tap hole. The sand used should be a rich heap sand riddled and at same temper as for molding. All new sand or sand too wet should not be used. It should be about 5 to 6 inches thick at the tap hole with a 1 to 2 inch pitch up toward the slag hole.

IV—LIGHT UP

(A) Flat wood is laid on top of bottom sand for protection while charging heavier wood. The wood usually is ignited through the tuyeres, or, better, by igniting oil-soaked rags and dropping them on the wood bottom from the charging door, then adding sufficient wood to thoroughly ignite the coke. About two-thirds to three-fourths of the coke used on the bed is then added and allowed to burn through until the bed is cherry red all over. The remainder of the coke is then added and leveled off ready for the charging operation.

(B) The coke bed should be high enough to give melted iron in from 8 to 10 minutes after blast is put on. This usually will require from 2,000 to 2,400 lbs., depending particularly on height of tuyeres above sand bottom and the shape of the cupola well. The above amount should bring the bed from 40 to 50 inches above tuyeres. In starting a new cupola, it is safe to use a coke bed 45 inches above upper edge of tuyeres. The upper edge of the melting zone is easily determined by examination of the lining after the first heat. It is a good plan to use a measuring rod for determining the height of the bed coke.

V—CHARGES AND CHARGING

All materials should be carefully weighed and loaded systematically according to size of pieces and composition. The proper system is best determined by experiment and practice. It is good practice to charge the heavy pieces around the lining of the cupola. This has a tendency to promote a better blast penetration.

Under ordinary conditions, the charges should be 2,000 to 3,000 lbs., and all alike. The charging may be done either by hand or by mechanical equipment of proper design. It is not the best practice to use mixtures of widely different compositions in the same heat. When this is necessary, separation of the mixtures may be partly accomplished by using an extra charge of coke at the point of separation.

VI—FLUX

A good grade of limestone should be used. For long heats and continuous melting, limestone amounting to from 2 to 4 per cent

of the weight of the iron charge, and 4 to 5 lbs. of fluorspar, should be used on each charge.

VII—BLAST[2]

The amount or volume of air required depends on the desired rate of melting, coke ratio and quality of coke. It is generally assumed that 30,000 cubic feet of air is required per ton of iron melted. The blast pressure varies according to style and size of tuyere openings, height of stack and size of coke and metal used in the charge. The pressure may vary from 6 ounces to 24 ounces, depending on the above conditions.

For uniform melting, the volume should be kept constant and the pressure allowed to vary. Every cupola should be equipped with volume and pressure gages and a means of adjusting the amount of air delivered into the wind box.

VIII—RECOMMENDATIONS

Any cupola should be operated on a fixed schedule. That is, a definite time for light up, for start of charging, for starting blast, for tapping out and for opening slag hole. The tap hole should be carefully gaged to promote desired rate of flow of molten iron, whether continuous or intermittent tapping is used. The blast should be maintained according to established foundry practice.

All materials used should be checked and recorded daily. In fact, to operate a cupola successfully, adopt a standard practice and stick to it. The only variations necessary are when there is a possibility of bettering the standard practice.

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[2] For a 54-inch cupola, one of the blower manufacturers recommends a machine having 22, 25 or 29 cubic feet displacement. That is, at each revolution of the blower 22, 25 or 29 cubic feet of air are supplied. In order to obtain 6,000 cubic feet per minute in accordance with the recommendation, it will be necessary to operate the blower at 6,000 divided by 22, 25 or 29 revolutions per minute; that is, 272, 240 or 206 r.p.m., respectively. Allowance for slippage must be made and this usually is taken to be 10 per cent. Therefore, the speeds will be 299, 264 or 227 r.p.m.

In using the blower as a volume meter, it is necessary only to know the displacement of the blower and the number of revolutions per minute. The manufacturer will provide the former figure and an ordinary tachometer can be used to determine the latter. In making the calculation, correction of 10 per cent for slippage should be included.

For instance, suppose the blower has a displacement of 25 cubic feet per revolution and the tachometer shows the number of revolutions per minute to be 250. Multiplying 250 by 25, we find that the blower is supplying 6,250 cubic feet per minute. This will be 10 per cent high because of slippage. Subtracting 625 from 6,250, we find that the air is actually being supplied at the rate of 5,625 cubic feet per minute, which is less than we desire. The remedy then is to speed up the blower to 264 r.p.m.

While the blower can thus be used as a volume meter, the element of slippage is difficult to determine accurately. Therefore, an instrument based on the principle of the standard orifice is recommended for accurate measurement of the air supply.

B—Recommended Methods for Calculation of Cupola Mixtures

In the calculation of cupola mixtures no set rule can be laid down because of the variations in the operation of cupolas. The following factors influence the control of some of the elements:

Blast pressure, volume, moisture and temperature.
Amount and character of coke used.
Depth of zone or well.

When working up calculations of the common elements in cast iron, be guided by the following:

Silicon (Si)—

Softens gray iron, opens up the grain, lessens density, and in excess weakens and hardens the metal and causes sponginess in heavy sections.

Sulphur (S)—

Hardens gray iron, closes the grain, increases density, and in excess causes defects, and may weaken the metal. Increases tendency to chill white in thin sections.

Phosphorus (P)—

Increases the fluidity of gray iron and in excess lowers the impact value. Fosters formation of porosity in heavy sections.

Manganese (Mn)—

Increases the density of gray iron. It has a strengthening effect up to around 1.00 per cent and in very small amounts has a softening effect. Over 1.00 per cent, has a tendency to harden gray iron.

Combined Carbon (CC)—

Increases hardness and toughness of gray iron. Increases strength below 0.80 per cent, decreases strength when in excess, closes the grain.

Graphitic Carbon (GC)—

Increases softness and machinability in gray cast iron, weakens, opens the grain, decreases density.

LOSSES AND GAINS TO BE CONSIDERED IN CALCULATING MIXTURES

Silicon.

Allow 10 per cent loss under normal conditions. When higher concentrated silicon alloys are added, the loss will be higher. The silicon loss in cast iron is due to oxidation. Silicon loss is controlled principally by the blast pressure, a high blast producing the maximum loss, and a low blast pressure producing the minimum loss, provided other conditions remain the same.

Sulphur.

Allow for 0.03 to 0.05 points increase. The sulphur increase is controlled principally by the kind of coke used. A low-sulphur coke (of 0.5 to 0.7 per cent) will produce the minimum result, and a high sulphur coke (0.7 to 0.9 per cent) will produce the maximum result.

Phosphorus.

This element remains practically constant; therefore, make no allowances.

Manganese.

Allow for a 20 to 30 per cent loss. Manganese loss is also due to oxidation. Mixtures having higher concentrated manganese alloys probably will show the maximum loss.

Carbon.

On account of many factors involved, it is difficult to calculate total carbon. Steel additions affect the amount of total carbon in cast iron. The character and amount of the coke, as well as the characteristics of the cupola, also influence the total carbon content.

METHODS OF CALCULATING

To illustrate the foregoing information, let us assume that we want to make up a 3000-lb. charge for heavy machinery castings containing 25 per cent steel and having the following composition:

Mixture No. 1

Silicon (Si)	1.35-1.40
Sulphur (S)	0.07-0.09
Phosphorus (P)	0.25-0.27
Manganese (Mn)	0.50-0.55

Or, let us assume that we want to make up a charge for light machinery castings containing no steel and having the following composition:

Mixture No. 2

Silicon (Si)	2.15-2.25
Sulphur (S)	0.07-0.10
Phosphorus (P)	0.45-0.50
Manganese (Mn)	0.55-0.60

The following stock is available in yard:

	Si	S	P	Mn
No. 2 pig iron	2.10	0.032	0.505	0.64
Malleable iron	1.80	0.033	0.165	0.75
No. 1 machinery scrap	1.90	0.085	0.405	0.60
Steel scrap	0.30	0.050	0.050	0.50
No. 1 pig iron	2.90	0.030	0.530	0.84

Returned scrap, gates, sprues, etc.

Keeping in mind the increases and decreases of the elements when making calculation, the following method can be used:

To get the above analysis we can use the following quantities from the above stock piles:

CALCULATION OF MIXTURE NO. 1

600 lbs. No. 2 pig iron, Erie brand
900 lbs. malleable iron, Albany brand
750 lbs. No. 1 machinery scrap
750 lbs. steel scrap

Silicon

600 lbs. × 2.10 = 1260 points
900 lbs. × 1.80 = 1620 points
750 lbs. × 1.90 = 1425 points
750 lbs. × 0.30 = 225 points

3000 lbs. 4530 points

4530 ÷ 3000 = 1.51

1.51 — 10% loss = 1.359%

Sulphur

600 lbs. × 0.032 = 19.20 points
900 lbs. × 0.033 = 29.70 points
750 lbs. × 0.085 = 63.75 points
750 lbs. × 0.050 = 37.50 points
3000 lbs. = 150.15 points
150.150 ÷ 3000 = 0.05005
0.05005 + 0.04 = 0.09005%

Phosphorus

600 lbs. × 0.505 = 303.00 points
900 lbs. × 0.165 = 148.50 points
750 lbs. × 0.405 = 303.75 points
750 lbs. × 0.050 = 37.50 points
3000 lbs. = 792.75 points
792.750 ÷ 3000 = 0.264%

Manganese

600 lbs. × 0.64 = 384 points
900 lbs. × 0.75 = 675 points
750 lbs. × 0.60 = 450 points
750 lbs. × 0.50 = 375 points
3000 lbs. = 1884 points
1884 ÷ 3000 = 0.628
0.628 — 20% loss = 0.5024%

Table 1

GRAY IRON CASTING CO.—MIXTURE FOR CUPOLA CHARGE.

Class of Castings *Heavy Machinery* Date

Brand	Pile No.	Pounds per charge	Per cent silicon	Pounds silicon	Per cent sulphur	Pounds sulphur	Per cent Phosphorus	Pounds Phosphorus	Per cent Manganese	Pounds Manganese
Erie No. 2.....	1	600	2.10	12.60	0.032	0.1920	0.505	3.030	0.64	3.84
Albany.....	3	900	1.80	16.20	0.033	0.2970	0.165	1.485	0.75	6.75
Machinery scrap....	5	750	1.90	14.25	0.085	0.6375	0.405	3.037	0.60	4.50
Steel.....	6	750	.30	2.25	0.050	0.3750	0.050	0.375	0.50	3.75
Totals.....		3000		45.30		1.5015		7.927		18.84
Percent charged....				1.510		0.050		0.264		0.628
Loss or gain.....				—0.151		+0.040				—0.126
Estimated analysis.				1.359		0.090		0.264		0.502

A daily record should be kept for all mixtures, and this can be done on a form sheet similar to that shown as Table 1.

CALCULATION OF MIXTURE No. 2

900 lbs. No. 1 machinery scrap
600 lbs. returned gates, sprues, etc.
1500 lbs. No. 1 pig iron

Silicon

900 lbs.	× 1.90	=	1710 points
600 lbs.	× 2.15	=	1290 points
1500 lbs.	× 2.90	=	4350 points
3000 lbs.			7350 points

7350 ÷ 3000 = 2.45
2.45 — 10% loss = 2.205%

Sulphur

900 lbs.	× 0.085	=	76.5 points
600 lbs.	× 0.10	=	60.0 points
1500 lbs.	× 0.03	=	45.0 points
3000 lbs.			181.5 points

181.5 ÷ 3000 = 0.0601
0.0601 + 0.04 = 0.1001%

Phosphorus

900 lbs.	× 0.405	=	364.5 points
600 lbs.	× 0.500	=	300.0 points
1500 lbs.	× 0.530	=	795.0 points
3000 lbs.			1459.5 points

1459.5 ÷ 3000 = 0.4865%

Manganese

900 lbs.	× 0.60	=	540 points
600 lbs.	× 0.55	=	330 points
1500 lbs.	× 0.84	=	1260 points
3000 lbs.			2130 points

2130 ÷ 3000 = 0.71
0.71 — 20% loss = 0.568%

A daily record should be kept for all mixtures, and this can be done on a form sheet similar to that shown as Table 2.

Table 2

GRAY IRON CASTING CO.—MIXTURE FOR CUPOLA CHARGE

Class of Castings *Light Machinery* Date

Brand	Pile No.	Pounds per charge	Per cent silicon	Pounds silicon	Per cent sulphur	Pounds sulphur	Per cent phosphorus	Pounds phosphorus	Per cent manganese	Pounds manganese
Machinery scrap....	5	900	1.90	17.10	0.085	0.765	0.405	3.645	0.60	5.40
Returned gates, spruces, etc.....	4	600	2.15	12.90	0.10	0.600	0.500	3.000	0.55	3.30
Erie No. 1.....	2	1500	2.90	43.50	0.03	0.450	0.530	7.950	0.84	12.60
Totals.....	....	3000	....	73.50	....	1.815	....	14.595	....	21.30
Per cent charged....	....	....	....	2.45	....	0.0601	....	0.4865	....	0.710
Loss or gain.....	....	....	....	−0.245	....	+0.04	....	....	....	−0.142
Estimated analysis.	....	....	....	2.205	....	0.1001	....	0.4865	....	0.568

At times we may desire to alloy our irons. Alloys such as chrome, nickel, molydenum, vanadium and titanium can be had in such form that they can be introduced in the spout or ladle.

High-silicon irons such as silvery iron (8.00 to 10.00 per cent silicon) and bessemer ferrosilicon (12.00 to 15.00 per cent silicon) can be had in pig form and mixed with the cupola charge when a higher silicon is wanted, provided the stock piles are such that the higher silicon could not be had without the introduction of one of the above high-silicon irons.

Ferrosilicon (50.00 per cent silicon) can be had in both lump and ground form. This alloy also is used to increase the silicon in cast irons. It is generally used in the ground form for ladle additions.

High-manganese irons such as spiegel (19.00 to 21.00 per cent manganese) can be had in pig form, and this is added to the charge in the cupola. Ferromanganese (80.00 per cent manganese) can be had in lump and ground form, the lump being added to the charge in the cupola and the ground form added to the ladle. These alloys are used when a higher manganese is wanted than could be had from the stock piles.

C—Recommended Analyses for Classes of Castings

Your committee, having been instructed to present recommendations covering representative analyses and mixtures for various classes of iron castings, accordingly submits herewith certain recommendations for consideration and criticism. *It is to be distinctly understood that these recommendations should not be interpreted as specifications and should not be used as such. It is to be understood further that good castings can be made which do not conform to these analyses.*

These recommendations are promoted as guides for the use of foundrymen desiring to have information for this purpose.

In considering the phosphorus contents, the committee wishes to state that it considers the question of phosphorus to be to some extent local, and that phosphorus may often be used with safety.

(1) AUTO CYLINDERS*

(a) *Plain Cylinder Iron—*

TC	3.25	Typical charge:	
Si	2.25	Pig iron	40%
Mn	0.65	Return scrap	40%
P	0.15	Steel scrap	20%
S	0.10		

* For auto cylinders the general practice is to run a Brinell hardness test in the bore—a desired hardness is 180 Brinell. Emphasis is further directed to obtaining a machinable iron (no hard corners or spots).

(b) *Alloy Cylinder Iron (chrome-nickel)—*

Analysis same as for plain cylinder iron, except alloy additions are made to obtain Ni 0.60, Cr 0.25, and a Brinell of 190 in the bore.

Typical cupola charge same as (a) and alloys added in ladle.

(c) *Alloy Cylinder Iron (high nickel)—*

TC	3.25	Typical charge same as (a)
Si	1.80	plain cylinder iron, except
Mn	0.70	alloy addition is made in
P	0.15	ladle.
S	0.10	Brinell hardness of 190 in
Ni	1.25	bore.

(2) FLY WHEELS (AUTO)

TC 3.25	Typical charge:
Si 2.10	Pig iron 40%
Mn 0.65	Return scrap.....40%
P 0.15	Steel scrap.....20%
S 1.10	

(3) PISTONS* (AUTO)

(a) *Plain Iron—*

TC 3.35	Typical charge:
Si 2.25	Pig iron 40%
Mn 0.65	Return scrap.....40%
P 0.15	Steel scrap.....20%
S 0.10	

* Same analyses as for plain cylinder iron.

(b) *Alloy (Molybdenum)—*

TC 3.35	Typical charge same as plain auto cylinder. Common practice to use a base mixture as for cylinder iron and alloy by ladle additions.
Si 2.25	
Mn 0.65	
P 0.15	
S 0.08	
Mo 0.35	

(4) BRAKE DRUMS (AUTOMOBILES, TRUCKS, BUSSES)

TC 3.30	Typical charge same as for plain auto iron—with alloys as ladle additions. The structure of the casting should be an all pearlitic iron with the desired Brinell hardness approximately 207.
Si 1.90	
Mn 0.65	
P 0.15	
S 0.08	
Cr 0.30	
Ni 1.25	

(5) GENERAL CASTINGS (AUTO)—SOFT IRON

TC 3.40	Typical charge:
Si 2.60	Pig iron.....50%
Mn 0.65	Return scrap.....45%
P 0.30	Steel scrap..... 5%
S 0.10	

(6) PISTON RINGS (AUTO)—(INDIVIDUALLY CAST)

TC	3.50	Typical charge:	
Si	2.90	Pig iron	60%
Mn	0.65	Scrap or sprue	40%
P	0.50		
S	0.06		

(7) AGRICULTURAL IMPLEMENT IRON

(a) *General (Medium Section)*—

TC	3.40	Typical charge:	
Si	2.10	Pig iron	35%
Mn	0.60	Steel scrap	10%
P	0.50	Scrap	55%
S	0.10		

(b) *Light Work*—

TC	3.50	Typical charge:	
Si	2.20	Pig iron	40%
Mn	0.55	Scrap and Returns	60%
P	0.70		
S	0.10		

(8) CHILLED PLOW IRON

(a) *Plow Shares*—

TC	3.60	Typical charge:	
Si	1.25	Pig iron	45%
Mn	0.55	Steel	15%
P	0.40	Returns	40%
S	0.10		

(b) *Mold Boards*—

TC	3.75	Typical charge:	
Si	0.85	Pig iron	45%
Mn	0.50	Steel scrap	15%
P	0.40	Returns	40%
S	0.10		

(9) MACHINERY IRON

	Light service or thin section (not over 1 in.)	Medium service or heavy section (1½ in.)	Heavy service with heavy section (2 in.)
TC	3.25	3.25	3.25
Si	2.25	1.75	1.25
Mn	0.50	0.50	0.50
P	0.50	0.50	0.50
S	0.09	0.10	0.10
Typical Charge:			
Pig Iron	50%	50%	50%
Steel	....	10%	25%
Scrap	50%	40%	25%

(10) HIGH-STRENGTH* CUPOLA IRON†

(a)

TC	2.75	Typical charge:	
Si	2.25	Steel scrap	85%
Mn	0.80	Return scrap	10%
P	0.10	Ferroalloys	5%
S	0.09		

(b)

TC	3.10	Typical charge:	
Si	1.25	Steel scrap	90%
Mn	0.85	Pig iron	8%
P	0.10	Ferroalloy	2%
S	0.09		
Ni	1.00		

* This iron, when tested in accordance with A.S.T.M. test, will show an average tensile strength of over 50,000 lbs. Brinell hardness on A.S.T.M. bar will run about 241.

† For purposes of machinability, nickel to amount of 1.00 per cent may be added.

(11) GAS ENGINE CYLINDERS

	Light	Medium	Heavy
TC	3.40	3.40	3.40
Si	1.75	1.50	1.25
Mn	0.80	0.80	0.80
P	0.35	0.35	0.35
S	0.09	0.09	0.09

Typical charge:

Pig iron	55%
Steel scrap	25%
Scrap	20%

(12) PIPE (ORDINARY SAND-CAST WATER PIPE)

	Light and Medium.	Heavy.
TC	3.60	3.40
Si	1.75	1.40
Mn	0.50	0.50
P	0.80	0.80
S	0.08	0.08

Typical charge:

Pig Iron	70%	60%
Return scrap	25%	25%
Steel	5%	15%

(13) SOIL PIPE

TC	3.40
Si	1.40
Mn	0.50
P	0.80
S	0.08

Typical charge:

Pig iron	70%
Return	30%

(14) HEAT-RESISTANT IRON (FIRE POTS, KETTLES, ETC.)

TC	3.50
Si	1.15
Mn	0.80
P	0.10
S	0.07

Typical charge:

Pig iron	70%
Scrap	30%

(15) INGOT MOLDS

TC	3.50
Si	1.00
Mn	0.90
P	0.20
S	0.07

Typical charge:

Pig iron	90%
Steel	10%

(16) CAUSTIC POTS

TC	3.60	Typical charge:	
Si	1.00	Pig iron	60%
Mn	0.75	Returns	40%
P	0.20		
S	0.07		

(17) CAR WHEELS

TC	3.35	Typical charge:	
CC	0.90	Pig iron	12.5%
Si	0.65	Steel	7.5%
Mn	0.60	Car-wheel scrap	80%
P	0.35		
S	0.12		

(18) WEARING PLATES

TC	3.20	Typical charge:	
Si	1.10	Car-wheel scrap	25%
Mn	0.85	Steel scrap	30%
P	0.35	Spiegeleisen	2%
S	0.17	Scrap	43%

(19) PRESSURE CASTINGS (AIR CYLINDERS, AMMONIA CYLINDERS)

TC	3.25	Typical charge:	
Si	1.25	Pig iron	50%
Mn	0.65	Steel scrap	25%
P	0.20	Return	25%
S	0.10		

(20) VALVES AND FITTINGS

TC	3.30	Typical charge:	
Si	2.00	Pig iron	50%
Mn	0.50	Steel scrap	10%
P	0.60	Scrap	40%
S	0.10		

Detecting Defects by Radiography, Using Gamma Rays*

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Abstract

A discussion is given of the use of gamma rays from radium for the detection of internal defects in steel castings. The characteristics of the method are briefly noted, and it is pointed out how the foundryman may apply them to the inspection and improvement of steel castings. The application of the method is illustrated by a series of radiographs taken on several castings. The film records are discussed, with particular reference to the effects of internal chills, and these records are correlated with the defects found upon a subsequent cutting up of the casting.

Introduction

1. The subject of defective steel castings has received considerable attention in the past, and, no doubt, will receive even more in the future. In fact, the increasingly more rigid specifications for steel castings seem to guarantee an increasing interest. Increasing strictness in specifications will lead inevitably to the production of better castings, and with the fact that possibly the chief fault with steel castings is lack of internal integrity, better castings will mean castings more nearly free from internal defects.

2. Accordingly, part of the problem of producing better castings consists in the elimination of casting imperfections, which requires the formulation of primary correct casting technique or principles, and of inspection technique necessary for the detection of internal defects.

Literature on Internal Defects Is Scarce

3. Upon delving into compiled data on faulty castings, one becomes impressed with the quantity of material that has been

* Published with the permission of the Navy Department.

† Division of Physical Metallurgy, Naval Research Laboratory.

written relative to surface or visual defects, and with the apparent lack of information available on the subject of internal defects. In one article alone it was shown that in a simple casting there was a possibility of 16 types of defects which could be identified visually.

4. It is reassuring to note that industry today has the manufacture of steel castings so controlled that surface defects have been largely eliminated, for industry has realized that the preponderance of surface defects are the result of carelessness in assembly of molds and cores and faulty mold construction.

Importance of Internal Contraction and Porosity

5. In a recent visit by the authors to a large number of steel casting producers, the subject of defects was invariably proposed as a subject requiring careful consideration. It was the opinion of these manufacturers that the most important problem confronting them, and one which presents considerable difficulty in attacking, is that of internal defects. These foundrymen agreed that internal contraction cracks and porosity unfortunately are exceedingly frequent and constitute the most important of the internal defects.

6. In order to determine the possible existence of internal imperfections, it is necessary to use other methods than those of visual inspection. The only widespread technique for the detection of internal defects is that of the use of a torch and a hack saw, possibly followed by machining, to render internal defects visible to the eye. While such methods have been used considerably in the past, they are not entirely adequate nor completely satisfactory.

Modern Methods of Studying Internal Defects

7. More satisfactory methods of inspection now are available. It is not necessary nor, indeed, advisable in many cases to destroy the casting to ascertain if defects are present. Furthermore, there is no need to hold up production of similar castings while waiting for machining to bring to light possible internal imperfections. These modern methods of inspection are chiefly X-ray and gamma ray radiography. This discussion is limited to radiography by gamma rays, because of its special adaptability to the steel casting industry.

8. Mehl, Doan and Barrett,[1] in 1930, showed the possible uses of gamma rays for the detection of defects in metallurgical materials. They also explored the physics of gamma rays from the standpoint of radiography and found that, with a sufficient source of radium, satisfactory radiographs may be taken of steel objects the thickness of which far exceeds that now possible with X-rays. A short time later Barrett, Gezelius and Mehl[2] discussed the technique for taking radiographs by means of gamma rays. In this paper charts were given and tables of exposure times listed for radium and radium emanation.

9. These publications have prepared the way for the use of the gamma ray as an aid to the steel foundryman in helping him search the interior of his pilot castings. However, before itemizing the distinguishing characteristics of gamma ray radiography, it would seem best to clarify the subject by reviewing briefly some of the major features.

Principles of Gamma Ray Radiography

10. The general principle involved in gamma ray radiography is identical with that in X-ray radiography, for both methods involve the use of light rays to penetrate opaque objects and produce shadow pictures. There is no difference in the fundamental nature of these two rays except that of wave length. The average wave length of the X-ray from a radiographic tube is about 0.15 ångstrom units, while the gamma ray is much shorter, with an average effective wave length of about 0.008 ångstrom units.

11. The efficiency of penetration that can be obtained is dependent directly upon the wave length of the ray. The shorter or "harder" ray exhibits the more effective penetration; in other words, a smaller portion of the light ray will be absorbed during the passage of the gamma ray through the opaque substances.

Practical Limits of X-Ray and Gamma Rays.

12. The practical limit of the X-ray, radiographically, as developed by a commercial high-tension bulb, is a thickness of

[1] Mehl, R. F., Doan, G. E., and Barrett, C. S., "Radiography by the Use of Gamma Rays,"; *Trans.* Amer. Soc. Steel Treating, vol. 18, p. 1192, 1930.

[2] Barrett, C. S., Gezelius, R. A., and Mehl, R. F., "The Technique of Radiography by Gamma Rays"; *Metals and Alloys*, December, 1930.

about 3½ inches of steel. Beyond this thickness the times of exposure become too long for practical purposes.

13. By using gamma rays, greater thicknesses than 3½ inches can be commercially and feasibly penetrated. The shorter wave length of the gamma ray permits an increase in thickness without the rapid increase in exposure time characteristic of X-rays. In fact, quite satisfactory radiographs have been obtained from penetration of the ray up to 10 inches of steel.[3]

Source of Gamma Rays.

14. It will be impossible to consider, in this paper, the physics of radium. This can be obtained in detail from the references cited above. It should be sufficient, however, merely to state that the source of the gamma ray is either a radium salt, contained in a small metal capsule, or radium emanation, a radioactive gas given off by radium which is held in a small glass capsule enclosed in a small metal container.

15. To make radiographs, this capsule is supported on a simple stand in front of the object to be tested, and ordinary X-ray films, in suitable light-tight containers, are fastened on the opposite side of the object. The exposure time depends on the

[3] Mehl, R. F., Doan, G. E., and Barrett, C. S., "Radiography by the Use of Gamma Rays"; *Trans.* Amer. Soc. Steel Treating, vol. 18, p. 1223, 1930.

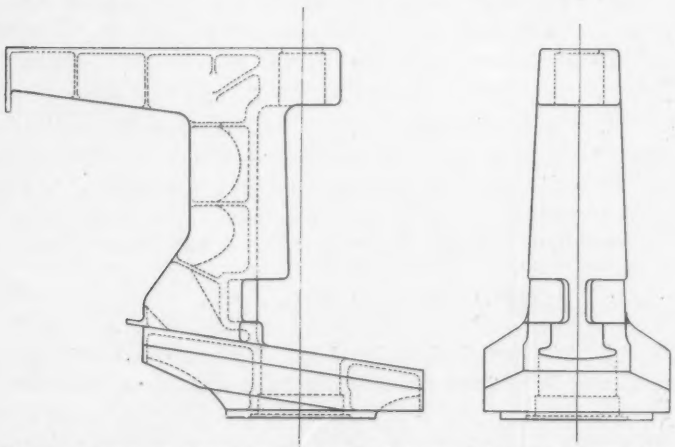

FIG. 1—SKETCH OF DEFECTIVE STERNPOST CASTING RADIOGRAPHED FOR DEFECTS. (SEE FIGS. 2 TO 12, INCLUSIVE, FOR RADIOGRAPHS OF VARIOUS SECTIONS.)

radioactive source, the distance from the source to the film, and the thickness and the nature of the object to be radiographed.

DEFECTIVE STERNPOST CASTING

16. A short time ago the laboratory was asked to radiograph a 9-ton casting that was located on the stern of one of the new 10,000-ton cruisers. A crack had developed in this casting after the casting had been installed. The crack was properly welded, but there was still some uncertainty as to the condition of the casting, and radiographs were taken while the ship was in dry dock.

17. In Fig. 1, a sketch of the casting is shown. The casting is extensively cored out, as is shown in the sketch. Little information is available as to the methods of manufacture. However, it is known that it was cast on the flat, that there were a number

FIG. 2—METHOD OF ATTACHING FILMS TO CASTING OF FIG. 1, BY SPOT WELDING WIRES TO CASTING. RADIUM WAS MOUNTED WITHIN CASTING. FOR IDENTIFICATION, LEAD NUMBERS WERE INSERTED BETWEEN CASTING AND FILM.

of large heavy heads used along the top surface and that the casting was double gated at the bottom. It was cast in a dry-sand mold, the cores being fashioned out of the same sand as was used for the backing sand of the mold. In general, it may be said that the casting averaged 1½ in. thickness throughout.

Manner of Attaching Films

18. The position of the films and their identification was obtained by inserting lead numbers between the casting and the film. The films were lightly attached to the side of the casting by

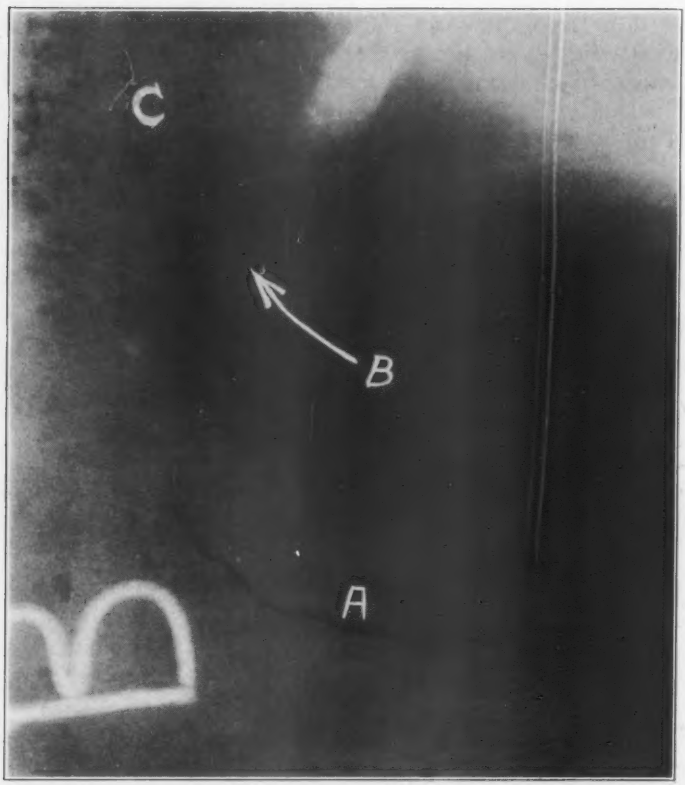

FIG. 3—RADIOGRAPH OF SECTION OF CASTING IN FIG. 1, SHOWING CRACK (*A*) 5 OR 6 INCHES LONG. BAND AT *B*, LEADING TOWARD LARGER AREA AT *C*, IS CHARACTERISTIC OF POROUS AREA OR EXISTENCE OF INCLUSIONS OR DIRTY METAL.

means of spot welding of wires in the manner shown in Fig. 2. In this way it was possible to take eight radiographs simultaneously, with the radium mounted within the casting.

19. One of the radiographs is reproduced in Fig. 3. In all work of this type, whether in X-ray or gamma ray radiography, the reproductions are never as well defined as the original films.

20. It may be mathematically demonstrated that, in the absence of scattering, the ability to detect a defect is independent of the thickness of the specimen. In practice, this relation holds approximately but not accurately, for scattering is present and

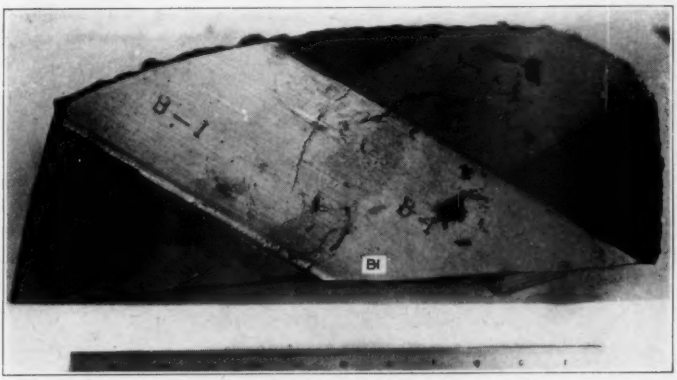

FIG. 4—CASTING SECTION OF FIG. 3, MACHINED, SHOWING BLOWHOLES, FINE POROSITY AND INCLUSIONS.

is a function of the thickness. Obviously, those parts absorbing the ray the more completely—that is, the thicker sections—show upon the film as light areas, while cavities or less absorbing parts cause dark areas on the film.

21. As the purpose of this paper is to discuss casting defects and their detection, only radiographs of defective castings are considered. Therefore, the following reproductions should not be used as an indication of the quality of steel castings in general. As a matter of fact, a large number of radiographs have been taken of steel castings upon which no defects can be detected.

22. Fig. 3 shows a crack (*A*) about five or six inches long. There is a band (*B*) above the crack that appears to be about

two inches wide which develops into a much larger area (*C*) in the upper left corner of the radiograph. This condition is characteristic of porous areas or inclusions or dirty metal.

23. Upon cutting up and machining this portion of the casting, all the defects that were noted in the film were found (Fig. 4). The band of defects as noted in the radiographs were found to be, as was assumed, small blowholes, fine porosity and inclusions. Some of these blowholes are shallow and others quite deep.

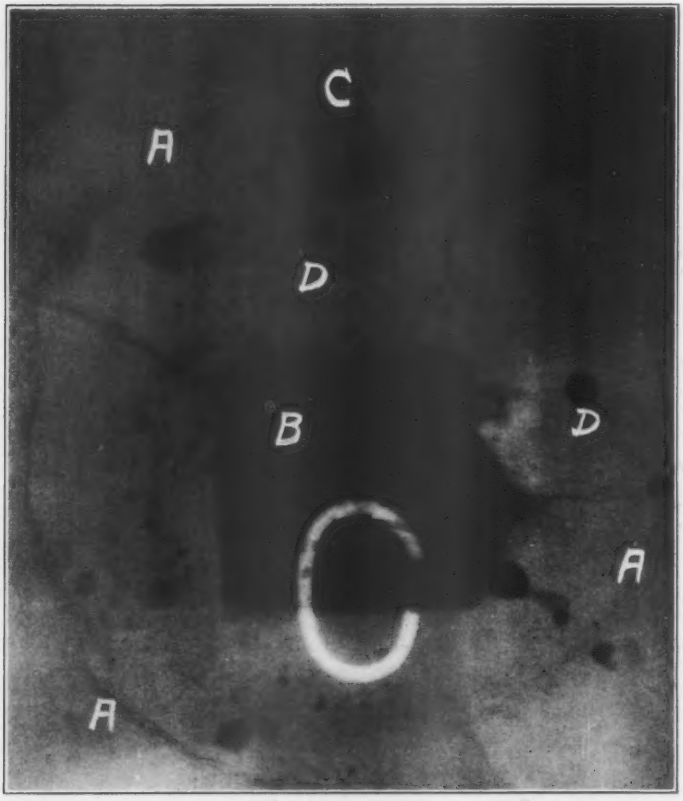

FIG. 5—RADIOGRAPH OF SECTION OF CASTING IN FIG. 1, SHOWING PRONOUNCED CIRCULAR SHADOW LINE (*A, A, A*) SURROUNDING DARK SQUARE (*B*). DARK SQUARE IS SURFACE DEPRESSION CAUSED BY CHIPPING OUT SQUARE WEDGE USED TO BUILD UP CHAPLET. *A* INTERPRETED AS A CRACK, *C* AS AN INCLUSION, AND ROUND DARK MARKS (*D, D*) AS BLOWHOLES AND AREAS OF POROSITY.

24. These features likewise are differentiated on the radiograph (Fig. 3) by the darker shadow markings. Other dark markings to the right of the crack are the result of porosity which is not shown in Fig. 4, as the machining was not carried far enough.

25. The section covered by radiograph of Fig. 5 shows a pronounced circular shadow line (*A, A, A*) surrounding a dark square (*B*). There are also numerous dark spots of varying intensities found close to and surrounding this cracked area. The dark square, however, is not in the metal but is a surface depression that was caused by chipping out a square sliver or wedge that was used to build up a chaplet.

26. In the interpretation of the remainder of the radiograph it was assumed that the circular line was a crack, that the round dark marks (*D, D*), both large and small, were blowholes and areas of porosity, and that the dark area (*C*) above the square and intersected by the crack was an inclusion of some type.

27. Fig. 6 shows the machined casting with the defects as shown in Fig. 5 brought to view. As can be easily seen, this crack

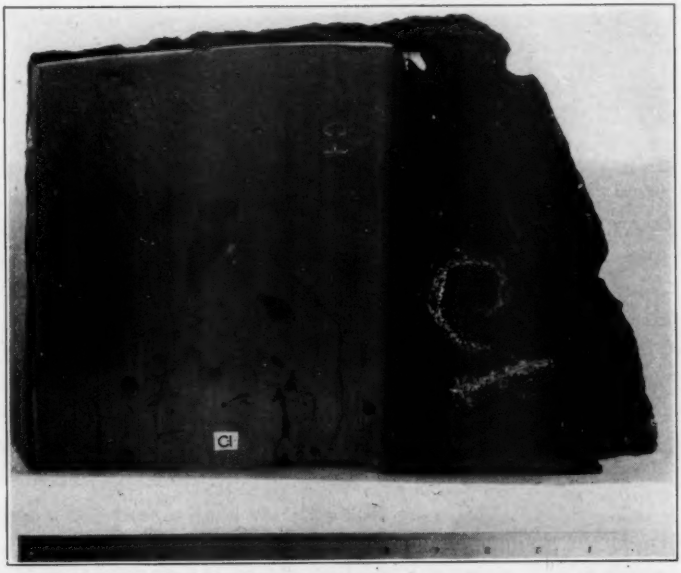

FIG. 6—CASTING SECTION OF FIG. 5, MACHINED, REVEALING (AS INTERPRETED FROM RADIOGRAPH) CRACK, SAND INCLUSION AND POROSITY.

as shown in the radiograph can be thoroughly identified. There is a considerable amount of porosity, and the defect that was assumed to be an inclusion proved to be a large sand inclusion.

28. The radiograph of Fig. 5 was taken of a portion of the cope side of the casting. If a visual examination had proved insufficient to identify the cope side of the casting, the radiographs taken would have disclosed it. This inference is based on the fact that slivers in the cope, represented by dark squares on the radiographs, were not fused into the metal, whereas the slivers in the drag were fused, for the casting was bottom poured and the drag slivers were in contact with hotter metal.

29. The presence of a considerable amount of porosity also is an indication that the position under consideration is part of the cope. If it had been in the drag, the gas would have been swept beyond the chaplet and not trapped by the rising metal as is shown so clearly by the machined specimen, and also by the radiograph.

30. Of course, this latter assumption is based on the fact that the porosity at this point owes its presence to the chaplet. It is not possible actually to prove this assumption, but when the conditions present are analyzed it seems not unlikely.

31. The casting was made in a dry-sand mold which in all probability was warm when assembled, and any moisture present consequently would condense on the cold chaplet. One drop of water heated to 2600 degs. Fahr. would have (if allowed to expand its normal amount) a volume about 8000 times as great as the drop from which it was formed. This fact shows that even the finest film of moisture on the chaplet would be more than enough to produce the porous conditions surrounding it.

32. When the crack that appears in Figs. 5 and 6 was studied, the first assumption was that it had been caused by the chaplet acting as a chill and producing a nucleus for solidification. The contraction crack was then, of course, the direct result of a too early cooling and contraction of a small area of the casting surrounded by hotter areas.

33. It was then suggested that the chaplet was not massive enough to produce such an effect, even though it did occupy a volume of 13.3 cu. c. and had a weight of 145 grams. If it is assumed that the metal had a temperature of 2800 degs. Fahr.

when it came in contact with the chaplet (such an assumption is not altogether unreasonable, as it has already been shown that the metal was relatively cold at this point), the calculations show that the heat content of about 3000 grams of molten steel is required (the heat furnished by cooling from the pouring temperature to that of incipient freezing) to fuse the chaplet into the casting—that is, to bring the temperature of the chaplet from room temperature to that of just molten steel.

34. In other words, the chaplet has acted as an effective chill over a concentrated area of 500 cu. c. Of course, the chill actually is spread over a much greater volume than this, as the

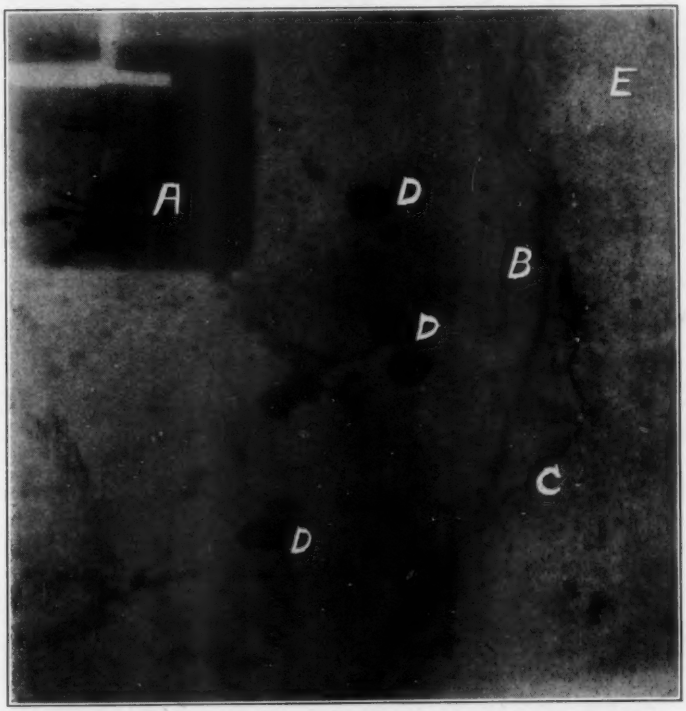

FIG. 7—RADIOGRAPH OF SECTION OF CASTING IN FIG. 1, TAKEN JUST BELOW PORTION CHIPPED OUT AND WELDED. FILM SHOWS SQUARE (*A*) SIMILAR TO ONE IN FIG. 5, LARGE CRACK OR HOT TEAR (*B*), SMALLER CRACK LEADING FROM *C*, AND BLOWHOLES AND POROSITY (*D*, *D*, *D*). LIGHTER AREA AT *E* IS DUE TO THICKER METAL, AS RESULT OF RUNNING WELD METAL DOWN OVER CASTING BEYOND CHIPPED-OUT CRACK.

temperature gradient probably follows an exponential course. The localized chilling effect produced by the chaplet therefore may be considered sufficient to cause the contraction crack observed.

35. The radiograph of Fig. 7 was taken just below that portion of the casting that had been chipped out and welded. This radiograph was prepared in order to see whether the crack had been entirely chipped out, but it is very evident that the chipping did not proceed far enough, as the extension of the crack can be easily seen from the radiograph.

36. In the radiograph, then, is another square (*A*) similar to the one seen in Fig. 5. This likewise proved to be a surface depression caused by the chipping out of a square sliver. The film shows what is undoubtedly a large crack (*B*)—or hot tear, as it more appropriately should be called—with a smaller crack (*C*) leading off from it (near the bottom of the radiograph). There are also numerous dark spots (*D*, *D*, *D*) of varying intensity that were assumed to indicate blowholes and the existence of porosity.

37. To the right of the square and near the top of the crack there will be noticed an area of a lighter intensity (*E*). This is due to a thicker metal at this part of the casting, and is the result of running the weld metal down over the casting beyond the chipped-out crack.

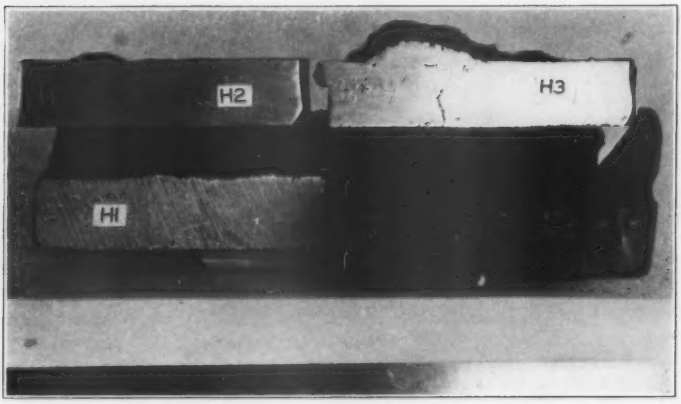

FIG. 8—CASTING SECTIONS OF FIG. 7, MACHINED ACROSS CRACKS. SECTION H-3 SHOWS WELD METAL DEPOSITED OVER THE CRACKS.

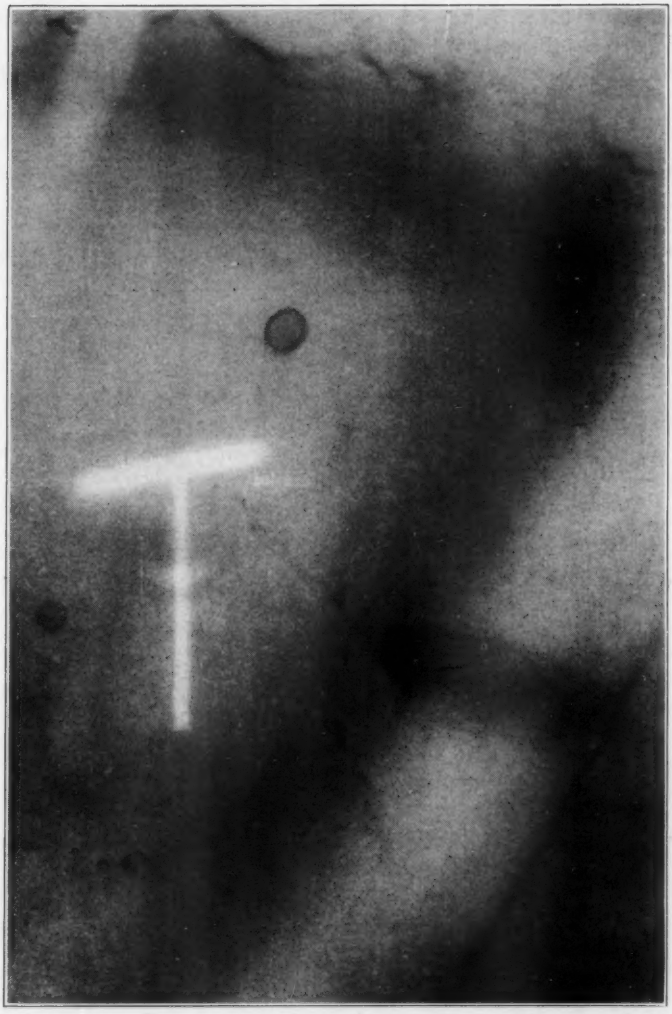

FIG. 9—RADIOGRAPH OF SECTION OF CASTING IN FIG. 1, TAKEN AT JUNCTION OF THICK AND THIN SECTION. NON-UNIFORM CROSS-SECTION CHIEF REASON FOR MAIN CRACK (AT TOP). DARK LINE IN LOWER RIGHT CORNER IS RABBET LINE ON SURFACE. TWO CIRCULAR DARK SPOTS ARE WATERMARKS IN NEGATIVE.

38. This condition shows up much better in Fig. 8. In H-3 of the machined casting it is possible to see the welded metal deposited over the cracks. The machined sections H-1, H-2 and H-3 were cut across the cracks so that it is not possible to follow the defects throughout in detail, but there is no doubt that the porous areas and gas pockets shown in the radiographs do exist.

39. This contraction crack is a continuation of the main crack, so it cannot be said that the presence of the chaplet was its primary cause for existence. However, its position in this section of the casting may have been determined by the cooling effect of the chaplet. The presence of the smaller, secondary crack very probably is due to the unequalized cooling set up by the chaplet. The porous area is very similar to the one found in Fig. 5.

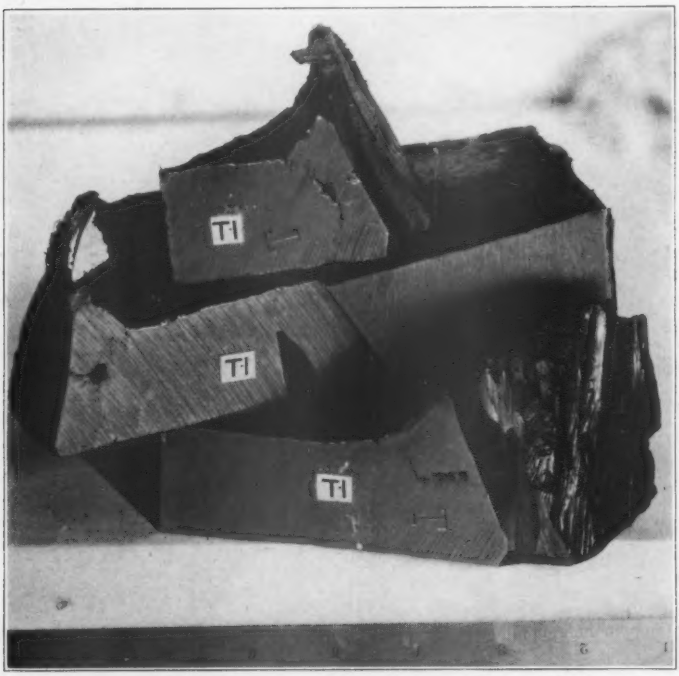

FIG. 10—CASTING SECTIONS OF FIG. 9, CUT UP AND MACHINED. CRACK SHOWS UP AS TYPICAL CONTRACTION CRACK, PROBABLY CAUSED BY IMPROPER FEEDING OF NON-UNIFORM CROSS-SECTION DURING SOLIDIFICATION.

40. The radiograph of Fig. 9 was taken at the junction of a thick and thin section of the casting. It may easily be seen that the non-uniform cross-section has been the chief reason for the existence of the crack. The main crack is seen to the extreme top of the film near the section of light intensity (greater thickness).

FIG. 11—RADIOGRAPH OF SECTION OF CASTING IN FIG. 1, SHOWING CRACK (*A*, *A*) AND PLACES (*B*) WHERE THREE HOLES WERE DRILLED IN CASTING AND WELD METAL IMPROPERLY INSERTED. DARK MARKINGS AROUND *B* INDICATE EXISTENCE OF POROSITY.

41. There are also some finer cracks under the large letter "T." The dark line cutting off the lower right-hand corner is a rabbet line on the surface of the casting. (The two small, circular dark spots are watermarks produced in the reproduction of the negative.)

42. When the casting was cut up, as shown in Fig. 10, the crack was very easily seen. It is a typical contraction crack in that it is very prominent in the interior of the metal and becomes finer as it extends to the surface. As is the case with most contraction cracks of this type, it extends to the surface but is so minute in character that surface inspection often fails to locate the defect. This crack undoubtedly exists because the non-uniform cross-section was improperly fed during solidification.

43. The section covered by the radiograph of Fig. 11 is rather interesting. A crack (*A*, *A*) is shown near the light area at the top of the radiograph. The three small circles (*B*) below the large letter "X" indicate places where three holes were drilled in the casting and weld metal inserted. The radiograph shows that the replacing of the weld metal was not properly done. It was also the supposition that a considerable amount of porosity existed near this area because of the series of dark markings.

FIG. 12—CASTING SECTION OF FIG. 11, MACHINED. CRACK NEAR RIB DOES NOT SHOW UP, AS MACHINING WAS NOT DEEP ENOUGH. POROUS AREA CLEARLY SHOWN.

44. Fig. 12 shows the section of Fig. 11 with a few machine cuts taken across it. The crack near the rib does not show up, as the machining has not been deep enough. The porous area, however, is shown.

45. One of the features noticed in this radiograph, in two of the other radiographs (Figs. 3, 4 and 7) and also observed in the machined specimens, is the existence of small portions of metal with voids along three sides. Such a condition can be noticed directly under the large letter "X" in Fig. 11. No attempt is made to explain these features, but some thought has been given to considering them as cold shuts, for their appearance leads one to believe such is the case. Their presence could have been removed from the casting if a higher pouring temperature had been used.

Result of Radiograph Examination

46. Approximately twenty-five radiographs of this type were taken of the casting, and in most instances poor quality of metal was indicated, especially on the cope side of the casting. After this radiographic inspection the cruiser put to sea, and during trials split the casting so badly that it shipped water. The cruiser then was compelled to dry dock for the replacement of the defective casting.

47. Obviously, there is no need to point out the fact that, had this casting been radiographed immediately after casting and prior to installation, it most certainly would not have been installed on the ship, and a saving of a very considerable amount of money and time would have been effected.

KEEL KNUCKLE CASTING

48. Our laboratory, at a later date, was asked to radiograph a keel knuckle casting which had shown a surface crack. The crack had been chipped out and welded and a report on the condition of the weld was desired.

Method of Attaching Films

49. The casting, owing to its shape and location, was comparatively easy to radiograph. The films were attached to the casting in the positions shown in Fig. 13 and the radium emanation supported in a glass funnel fastened to a sawhorse at such a

distance from the film that an overnight exposure could be used. The white portion shown on the casting indicates the position of the weld.

50. In Fig. 14, film section "A" of Fig. 13, a series of cracks (*A*, *A*, *A*) may be seen running diagonally across the film. Below the cracks, and to the left, a slight indication of porosity (*B*) is shown.

51. Fig. 15, film section "D" of Fig. 13, shows the beginning of a large shrinkage crack (*A*) which is about one-half inch wide and extends through film sections "E" and "F" and "H" (Fig. 13), having an overall length of approximately three feet. Above the crack, what appears to be sand inclusions (*B*) may be seen. The thickness at the lower part of the film, at the location of the crack, is 5 inches, and at the lower left-hand corner, 7 inches. The darker area in the upper right-hand corner is due to a sharp reduction in thickness.

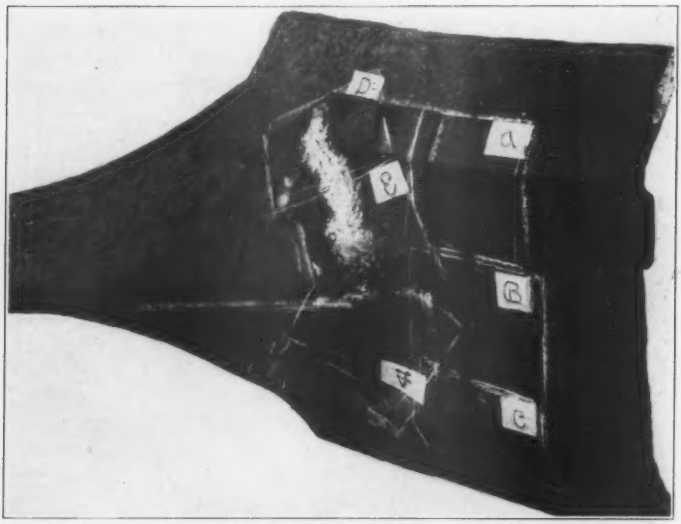

FIG. 13—KEEL KNUCKLE CASTING, SHOWING POSITIONS IN WHICH FILMS WERE ATTACHED TO CASTING FOR RADIOGRAPHS. RADIUM EMANATION WAS SUPPORTED IN GLASS FUNNEL FASTENED TO SAWHORSE AT SUCH DISTANCE FROM FILM AS TO GIVE OVERNIGHT EXPOSURE. WHITE AREA NEAR "D" AND "E" INDICATES POSITION OF WELD. (SEE FIGS. 14 TO 17, INCLUSIVE, FOR RADIOGRAPHS OF VARIOUS SECTIONS.)

52. A continuation of the crack is shown in Fig. 16. The crack above is the main crack that extends entirely across the casting. The crack below is confined to this film and has a length of about ten inches. As is readily seen, there are numerous fine cracks extending between the two major ones, and a considerable amount of porosity also is present. The thicknesses at the lower portion of the film at the points of the crack, and at the upper left-hand corner, are 4½ inches and 6 inches, respectively.

53. A 1-inch hole was drilled into the casting and the lower

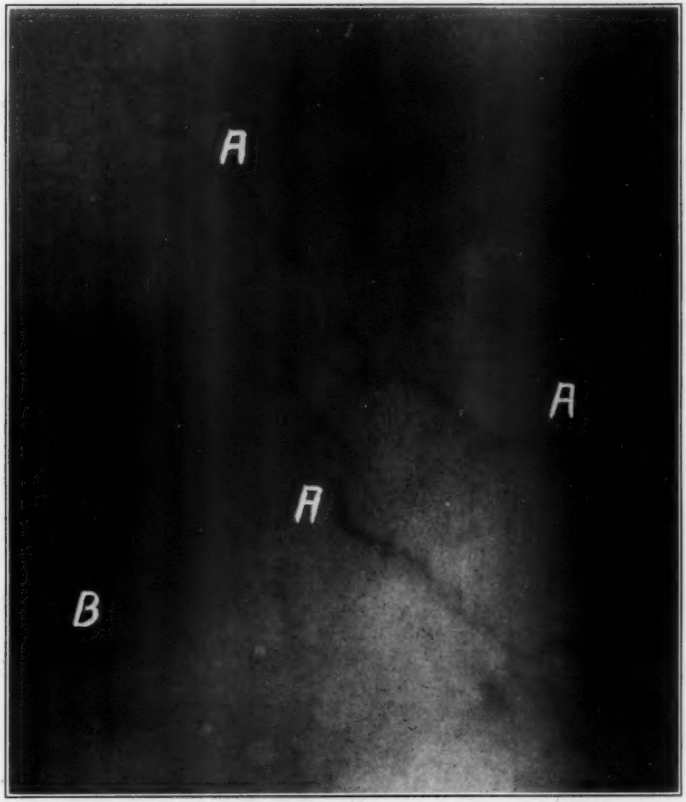

FIG. 14—RADIOGRAPH OF SECTION "A" OF CASTING IN FIG. 13, SHOWING SERIES OF CRACKS (*A*, *A*, *A*) AND SLIGHT INDICATION OF POROSITY AT *B*.

crack exposed at a depth of 1½ inches. Its width, as assumed from the films, was found to be about one-half inch.

54. Fig. 17, film section "H" of Fig. 13, shows the end of the main crack (*A*), several minor cracks (*B*) extending down below it. The thickness at the lower left-hand corner is two to three inches. The light portion at the right (*C*) is caused by a comparatively heavy section.

55. The weld appeared to be sound, as all of the cracks found were located to the left of and below the welded surface crack.

FIG. 15—RADIOGRAPH OF SECTION "D" OF FIG. 13, SHOWING BEGINNING OF LARGE SHRINKAGE CRACK (*A*), APPROXIMATELY ½ INCH WIDE AND 3 FEET LONG, EXTENDING THROUGH FILM SECTIONS "E," "F" AND "H" OF FIG. 13. SAND INCLUSIONS APPARENTLY VISIBLE AT *B*.

OBSOLETE GUN SLIDE CASTING

56. Recently an obsolete 5 inch gun slide was radiographed. Fig. 18 shows the location of the films and the stand for holding the radium emanation. If defects were present, they were expected at the points of non-uniform cross-section, where feeding was rather difficult. So far as the method of manufacture is

FIG. 16—RADIOGRAPH OF SECTION "F" OF FIG. 13, SHOWING (BELOW) CONTINUATION OF SHRINKAGE CRACK ABOUT 10 INCHES LONG, AND (ABOVE) MAIN CRACK EXTENDING ENTIRELY ACROSS CASTING. NUMEROUS FINE CRACKS AND CONSIDERABLE POROSITY ALSO SHOWN.

concerned, it is known that the casting was made on the side, that a large head ran completely through the casting to feed the trunion in the drag side, that other small heads were placed at advantageous points, and that the casting was gated at the bottom.

57. The radiograph of Fig. 19 was taken of the varying cross-section at the base of one of the recoil cylinders. This portion of the casting showed weaknesses, as is well exemplified by the existence of the hot-tear cracks. The casting was machined (Fig. 20), and the cracks were all located.

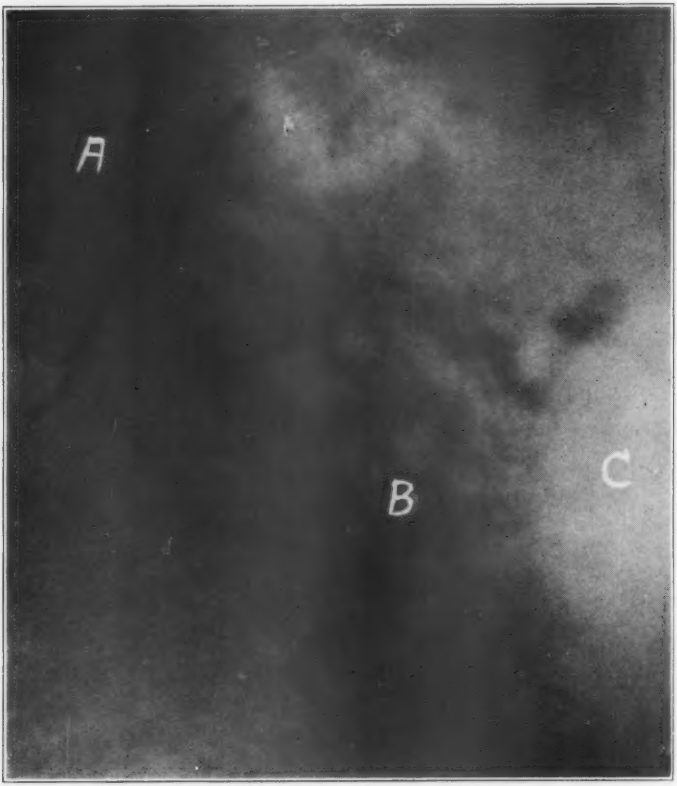

FIG. 17—RADIOGRAPH OF SECTION "H" OF FIG. 13, SHOWING MAIN CRACK (*A*) AND SEVERAL MINOR CRACKS (*B*) BELOW. LIGHT SECTION AT RIGHT CAUSED BY COMPARATIVELY HEAVY SECTION.

58. This is a perfect illustration of that well-known principle in casting technique that it is impossible to have a variable cross-section with improper feeding and still produce a sound casting, free from contraction cracks. In this case the 3½-inch thick section is that portion in which the cracks formed. On either side of this area the thickness decreased to a 2-inch section. Cracks were found in both of the recoil cylinders, one more pronounced than the other. This was probably the result of poorer feeding.

EQUIPMENT USED

59. The films used for the radiographs shown in this paper were Eastman Duplitized Contrast films. An exposure and development to give an absolute density of 2.20 were used throughout, as such a density is sufficient to show any defect which has a depth of 2 per cent or more of the total thickness of the piece.

ADAPTABILITY OF GAMMA RAY RADIOGRAPHY TO CASTING MANUFACTURE

60. It is believed that radiographic methods should be used not only for the purposes of inspection but also by foundrymen and designers as a method for establishing the correct technique to procure sound castings.

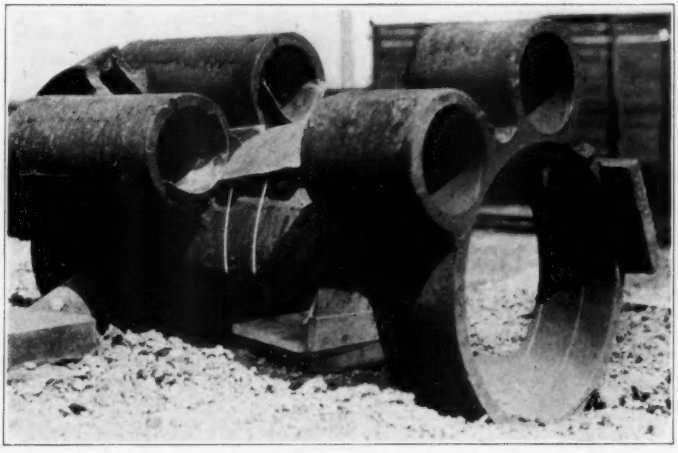

FIG. 18—OBSOLETE GUN SLIDE, SHOWING LOCATION AND MANNER OF ATTACHING FILMS FOR RADIOGRAPHS.

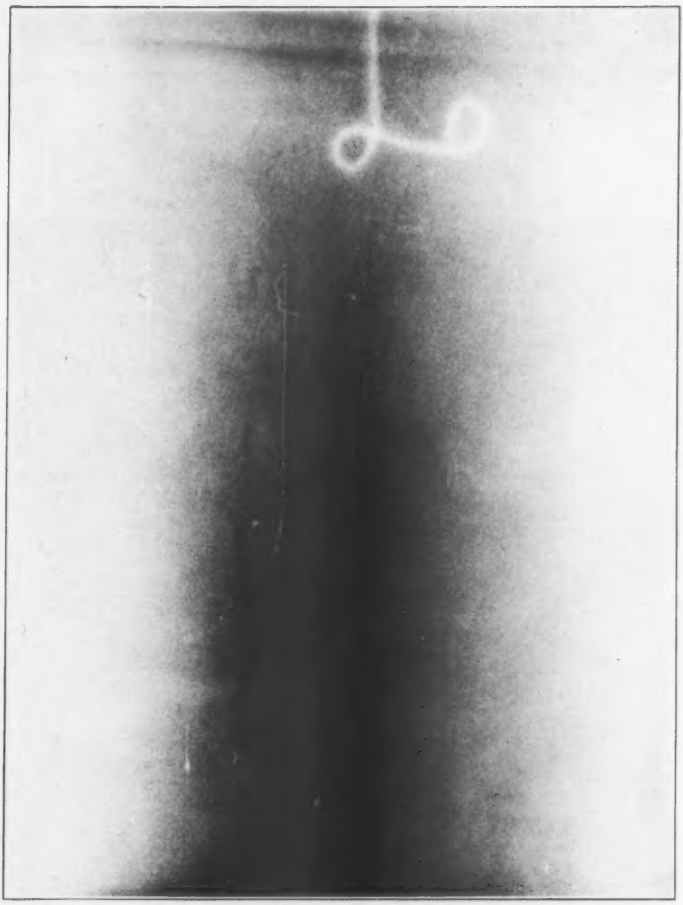

FIG. 19—RADIOGRAPH OF SECTION OF CASTING IN FIG. 18, TAKEN OF VARYING CROSS-SECTION AT BASE OF RECOIL CYLINDER. WEAKNESS IS SHOWN BY PRESENCE OF HOT-TEAR CRACKS.

61. As a method for the detection of casting defects, the gamma ray offers three advantages that the foundryman should not overlook, namely, (a) portability, (b) simplicity in operation, and (c) great penetration. If it had not been for the facilities of ease in portability, the radiographing of the sternpost casting could never have been done, as the job required a non-destructive examination of the casting in place.

62. The great penetration that is attained by the gamma ray makes it possible to examine such castings as that of the keel knuckle casting where thicknesses of three to seven inches or more must be penetrated, and where no other method of non-destructive testing can be used.

63. The lack of sensitivity of the gamma ray method to the changing of casting thicknesses makes it possible to prepare well-defined radiographs such as those of the keel knuckle casting, where the cross-section varied from five to seven inches and four to six inches, respectively. Perfect definition likewise is attainable on smaller castings of varying cross-sections.

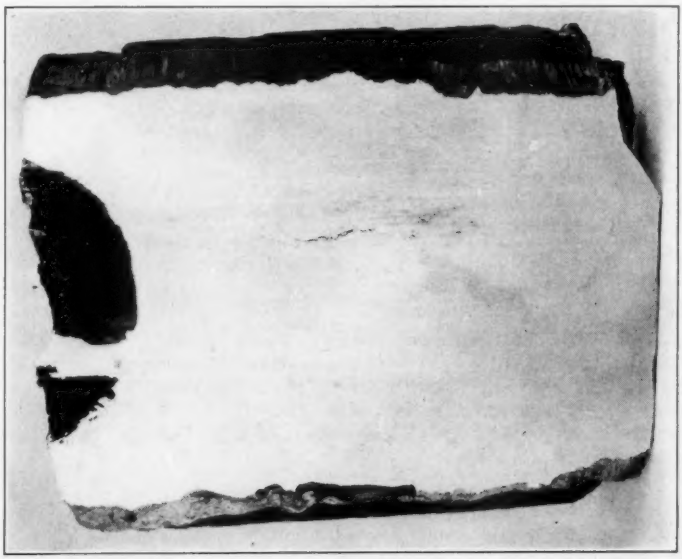

FIG. 20—CASTING SECTION OF FIG. 19, MACHINED, SHOWING CRACKS ALL LOCATED. CRACKS FOUND IN BOTH RECOIL CYLINDERS, PROBABLY AS RESULT OF IMPROPER FEEDING OF VARIABLE CROSS-SECTION.

64. The simplicity of operation makes it a ready tool for the use of the foundryman, for no elaborate apparatus is required. There is no reason why the method should not be applied as soon as the casting is cool enough to handle.

65. All in all, radiography by the use of gamma rays seems to be a useful tool for the foundryman and should lend real assistance in the detection of internal defects and in the study of the conditions leading to the production of defects with the object of preventing their occurrence.

ACKNOWLEDGMENT

66. The authors wish to express their obligation to Dr. Robert F. Mehl and Dr. Charles S. Barrett of the Division of Physical Metallurgy, Naval Research Laboratory, for the valuable assistance they rendered in the preparation of this paper. To J. E. Crown, Master Mechanic of the steel foundry of the U. S. Naval Gun Factory, our gratitude is due for the consideration and help which he extended.

DISCUSSION

O. W. BRINSON:[1] I am very familiar with the stern-post job described by the authors. We did not make the first casting mentioned, but we did make the second casting. There is no question in my mind but that gamma radiography is the coming thing in the steel industry, as explained.

This particular casting and the radiographs describing it were made after the rupture occurred. The casting was and is subjected to enormous strain. It is the stern post that carries the rudder. The test applied to the casting is that, when the ship proceeds at full speed ahead, the stern post has to throw the rudder over full port or full starboard, which puts an enormous strain on the casting.

This casting we now have at the Yard, cut up. It shows, on chemical analysis, 0.35 per cent carbon and 0.38 per cent silicon, with a nickel content of 3.5 per cent. It is our opinion that, perhaps in keeping with Mr. Melmoth's point, one of the points which he raised was that of the metal itself being bad, and that the manufacturer in making the casting

[1] Master Molder, Norfolk Navy Yard, Norfolk, Va.

probably had tried to eliminate carbon too quickly and killed it too quickly with silicon, which accounts for the high silicon content.

In examination of the casting, the casting first cracked and was then welded, and on the second test another crack occurred outside of the weld. It came under the weld, cracked up through the weld and then went on on top of the weld. A general examination showed that the break itself was not characteristic of good steel properly annealed, and a casual examination of the crack shows very few blowholes to cause the crack. The blowholes were there in the casting but in such locations that they, in themselves, never would have caused the failure of the casting.

I took a piece of the casting, cut it up and put it on a block such as we break our test bars on for the electric furnace, and with three blows of the sledge hammer broke it. A test bar cut close to the crack showed elongation of 15.5 per cent against 22 per cent specified, and a reduction in area of approximately 21.5 per cent against 35 per cent specified. This showed the metal was not in accordance with specifications, although the test bar annealed with the casting apparently did come up to specifications.

We replaced this casting with a heat made in an electric furnace of chrome-nickel, containing 1.5 per cent nickel and 0.6 per cent chrome. This latter casting has been installed in the ship and put under test, and it carried the Secretary of Navy down to Panama and back without any defects at all.

The second casting described in this paper is a keel knuckle for the new cruisers. Extreme care had to be taken in making this casting.

The casting made in the Navy Yard showed that the construction should have been perfectly satisfactory; neither the cracks nor the porosity were such that the casting was affected. It ran from a box section probably 10 inches wide and about the same depth to a section 4 feet wide by 1½ inches thickness, and, passing from the narrow section to the wide section they had to go through a heavy section of metal tapering from 7 inches thick in some places and 2 or 3 feet wide, and in a place hard to find. This, of course, would cause porosity, which might be the cause of considerable trouble.

If the structure could have been designed so as to go through a box section instead of the solid metal at that point, the trouble would have been eliminated and a casting produced just as strong as required.

CHAIRMAN JOHN HOWE HALL:[2] In connection with these new methods of inspection—X-ray, gamma ray, etc.—although they undoubtedly are going to be used very much, especially for pilot castings, the experimenters must remember a remark that I heard H. M. Howe make one time in arguing with Professor Fay about how extensive some non-metallics are in rails. Mr. Howe got nettled and said: "You must remember, Professor Fay, that after all a microscope is an instrument for finding what you are looking for."

With these rather delicate methods of inspection such as radiography, it is probable, in almost any mean section of a casting, if a man goes

[2] Technical Assistant to President, Taylor-Wharton Iron & Steel Co., High Bridge, N. J.

after defects of porosity and slight cracks, he is going to find them. There must be a great deal of judgment used in determining the seriousness of those cracks.

I remember the Watertown Arsenal's reports made when first they were going ahead with the X-ray. They reported every time that, by a change in the foundry method, they had learned to eliminate the defect. However, after a year or so, I noticed they swung around to say that changes in foundry practice had been made which put the defect in a place where it did not do much harm.

Some Effects of Nickel on Bronze Foundry Mixtures

By N. B. Pilling* and T. E. Kihlgren,* Bayonne, N. J.

Abstract

Following a very brief discussion of the general action of nickel in foundry bronzes, results are given of tests designed to develop the extent to which the strength properties of sand castings of a number of commonly used mixtures are modified by contents of nickel up to 3 per cent. The effect of pouring temperature on these mixtures is also developed in detail. Every one of the mixtures responds favorably to small contents of nickel, and in some cases the resistance to incipient deformation is greatly increased with an associated increase in ductility. The best nickel contents differ considerably, depending upon the nature of the base mixture.

1. The commercial bronze foundry alloys consist of an almost innumerable variety of combinations of zinc, tin, lead, phosphorus and even other elements with copper. While the alloys in common use are so numerous, the greater part of the requirements of users of bronze castings is met by some half dozen or so somewhat loosely standardized types of mixture. In dealing with these, the foundryman is accustomed to a considerable amount of latitude in the adjustment of composition, and reaches satisfactory compromises in casting properties, physical properties and cost by the intelligent manipulation within reasonable limits of these elements.

2. The useful qualities of these mixtures depend not only on the proportion of the component elements present but to an important degree upon conditions under which the castings are produced, including the size and nature of the casting, type of mold, temperature of pouring and other factors. The complexity of all these conditions serves as an effective deterrent to the systematic study of this important group of engineering materials.

3. Nickel is commonly present as an auxiliary modifying element in many bronze foundry mixtures for the purpose of ac-

* Bayonne Laboratory, The International Nickel Co., Inc.

complishing any of several purposes. It is proposed to recall in this paper some of the reasons why nickel has been found useful in these casting alloys, and to discuss in some detail the effects of nickel on a group of important strength properties.

NICKEL MODIFIES MANY PROPERTIES OF BRONZES

4. For convenience, it is possible to consider nickel as having two principal kinds of action in bronze casting alloys, namely:

1—Beneficial changes in physical properties and productive facility.

2—Development of a white color and improvement in corrosion resistance.

Physical Properties and Production.

5. The first group is, as a rule, concerned with rather small percentages of nickel, generally under 10 per cent and frequently as low as 1 per cent or less. The second group is related with higher percentages of nickel, almost always in excess of 10 per cent; these white, corrosion resistant bronzes are, in fact, the casting grades of nickel silver, with which our present interest is not concerned.

6. The copper-tin and copper-zinc series of alloys form the elemental basis of the casting bronzes, and the effect of small contents of nickel on the complex foundry alloys may be roughly forecast from the action of nickel on these two simple series.

7. Nickel is completely miscible in *alpha*-range copper-zinc alloys, even to the complete replacement of the copper content by nickel. That is to say, the presence of nickel leads to the development of no new constituent, and the zinc content marking the first appearance of the *beta* phase is but scarcely changed by the presence of even 20 or 30 per cent of nickel.[1]

8. In this case nickel, in solution, has its principal physical effect as a combined strengthening and toughening agent, frequently leading to an increase in ductility. On the other hand, the *alpha*-range of the copper-tin alloys is sharply restricted by nickel,[2,3] and not only does the *alpha-delta* eutectoidal constituent appear at lower tin contents as the nickel content rises, but a num-

[1] O. Bauer & M. Hansen; *Zs. Metallkunde*, vol. 21, p. 357, 1929.
[2] W. B. Price, C. G. Grant & A. J. Phillips; *Trans.* A. I. M. E., p. 503, 1928.
[3] E. M. Wise, discussion of above.

ber of as yet obscure structural changes occur,[4] including the appearance of new phases and the disappearance of the eutectoidal structure within the *delta* constituent.

Tin Complicates Effects of Nickel

9. It is evident that in the presence of tin the effects of nickel may thus become quite complicated. The principal physical effect in this case is a strengthening one, which may at first be accompanied by a rise in ductility but may also be followed by a loss of ductility with a sufficiently high content of nickel.

10. Very roughly, equivalence in gross structure follows the substitution of nickel for a like amount of tin, and the desirable tin contents in bronzes containing much nickel are considerably less than in the simple bronzes.

11. The strengthening and toughening effect of nickel is an important one and will be dealt with in detail later in this paper. A number of investigators [5, 6, 7, 8, 9, 10] have made scattering observations on this useful effect, which have resulted in a not inconsiderable use of nickel bronzes in industry. Bronzes containing 5 to 10 per cent nickel retain their strength more completely at moderately high temperatures than do the simple bronzes, and a number of special mixtures for use in valves in steam engineering take advantage of this quality.

Nickel Raises Bronze Melting Point

12. Nickel quite generally raises the melting point of bronzes. A recent laboratory study shows the increase in liquidus temperature to be about 12 degs. Fahr. per 1 per cent nickel content if nickel replaces copper, or 32 degs. Fahr. per 1 per cent nickel content if nickel replaces tin.

13. Owing to a peculiar property not well understood, this does not develop a limit to its use, as in a number of cases nickel has been found to increase the fluidity of foundry bronzes, permitting either lower pouring temperatures in the face of a rise

[4] C. Upthegrove, G. Wilson & F. N. Rhines; *Trans.* A. S. T. M., vol. 30, p. 572, 1930.
[5] F. Johnson, *Journal*, Inst. Metals, vol. 20, p. 167, 1918.
[6] L. Guillet, *Chem. & Met. Engr.*, vol. 24, p. 261, 1921.
[7] G. F. Comstock, *Journal*, Inst. Metals, vol. 36, p. 206, 1926.
[8] W. M. Corse, *Journal*, Inst. Metals, vol. 36, p. 207, 1926.
[9] T. H. W. Jeacock, *Inco*, vol. 7, p. 20, 1927.
[10] Anonymous, *Iron Age*, March 4, 1926.

in melting point, or advantage to be taken of rather high nickel contents without loss of fluidity. This has been found to be the case in practical foundry operations, and has been confirmed in laboratory tests directed to the point.

Effect on Other Casting Properties

14. A number of the casting properties of bronze mixtures, in addition to fluidity, are changed by small contents of nickel. Many of these are difficult to demonstrate experimentally but rest upon the practical observation of many foundrymen who have found useful effects to result from the inclusion of small percentages of nickel in their mixtures.

15. In this class are its densifying action, which is believed to facilitate the production of pressure-tight hydraulic castings, and its action in refining the grain and fracture of castings. Both of these effects may be manifestations of a tendency to minimize the incipient shrinkages described by Bolton[11] and many others.

16. In some cases a reduction of grain size and a marked increase in specific gravity have been noted to follow the introduction of nickel, although special attention to deoxidation appears to become necessary if the nickel content exceeds a few per cent. The effect of nickel in neutralizing unsoundness resulting from very small contents of silicon and aluminum in a low tin content leaded bronze has been described,[12] but otherwise there is little available information directed particularly to these obscure but useful actions.

17. The assistance received from nickel in effecting the dispersement of lead in highly leaded bronzes is well-known, and some measurements have been made of the effect of nickel on the rate of wear of bearing bronzes.[13]

EFFECT OF NICKEL ON TENSILE AND COMPRESSIVE PROPERTIES OF SIX SAND-CAST MIXTURES

18. A group of mixtures representing the types having general industrial importance has been selected upon which to show the effect of nickel on strength properties. Simple as the conception may be of changing the properties of a bronze casting alloy

[11] J. W. Bolton & S. A. Weigand; *Tech. Publ. No. 163*, A. I. M. E., 1929.

[12] H. M. St. John, G. L. Eggleston & T. Rynalski; *Tech. Pub. No. 300*, A. I. M. E., 1930.

[13] E. M. Staples, R. L. Dowdell & C. O. Eggenschwiler; *Journal*, S. A. E., vol. 27, p. 45, 1930.

by the inclusion of a special element, such as nickel, the demonstration of such effects is not particularly easy, owing to the well-recognized fact that many factors other than composition determine the quality and usefulness of a casting, and the accentuation of the effect of a minor compositional change requires the close control of many foundry conditions to a considerably greater degree than is necessary in ordinary foundry operations.

Mixtures Tested

19. The mixtures under study were as follows:

1—An 11 per cent tin-bronze of the type commonly used in worm gears.

2—A red brass—the common 85-5-5-5 mixture.

3—A yellow brass containing 1 per cent tin, 2 per cent lead.

4—G-bronze with 8 per cent tin, 4 per cent zinc.

5—The common 80-10-10 leaded bearing bronze.

6—A high lead content bearing bronze of the type used for locomotive brasses, with 6 per cent tin, 20 per cent lead.

20. In all of these mixtures nickel was introduced to replace a like amount of copper, the zinc, tin, lead and phosphorus contents remaining unchanged. Comparisons were made between a control melt free from nickel, and others containing nickel substitutions of approximately 0.5, 1.5 and 3 per cent.

Method of Making Tests

21. The melts were approximately 150 lbs. in weight and were made entirely from new metals of high quality. These were ingot copper, ingot tin and lead, "Horsehead" zinc, electrolytic nickel and 15 per cent phosphor-copper. In a few cases the nickel content was supplied as 50 per cent cupro-nickel, previously prepared from electrolytic nickel.

22. The copper and nickel were melted down under a charcoal cover in crucibles in a pit furnace fueled with low sulphur content oil and with a slightly oxidizing flame. After fusion, tin and zinc were added, the lead addition being delayed until just before the pot was ready for withdrawal from the pit. Before pouring, the melts were deoxidized with about 0.05 per cent phos-

phorus and vigorously stirred with a graphite rod. The composition of these experimental heats is given in Table 1.

23. After experimentation with a number of designs of test casting, including variations in gating and disposition of risers, the pattern shown in Fig. 1-*A* was chosen for tension test specimens. This developed a good combination of properties which could be satisfactorily reproduced in check melts.

24. The test specimen was standard, threaded-end, 0.505 in. diameter machined from these blanks, the outer skin of the casting being removed. The compression test specimen consisted of a cylinder of 1 in. diameter, 2 in. long, with parallel ends, machined from the core of a large cast cylinder (Fig. 1-*B*) near the base.

Table 1

COMPOSITION OF NICKEL BRONZE MIXTURES

Type	Heat No.	Analysis Cu	Ni	Sn	Zn	Pb	P	Note
Gear Bronze	1	88.67	tr	11.38	....	....	.030	*a*
	2	88.70	.03	11.12	....	....	.026	*b*
	3	88.26	.47	11.03	....	....	.030	
	4	87.14	1.47	11.34	....	....	.021	
	5	85.82	2.94	11.13	....	....	.013	
G-Bronze	6	87.95	.02	8.39	3.57	....	.027	
	7	87.67	.58	7.91	3.66	....	.028	
	8	86.13	1.70	8.43	3.65	....	.047	
	9	85.11	3.21	7.90	3.60	....	.036	
	10	82.64	5.32	7.96	4.02	....	.015	*c*
Red Brass	11	83.85	.03	4.83	5.22	6.01	.036	
	12	83.60	.48	4.93	5.07	5.83	.036	
	13	81.93	1.60	5.12	5.14	6.13	.036	
	14	81.30	3.03	5.00	4.65	5.94	.040	
Yellow Brass	15	70.90	.03	1.08	25.22	2.60	.037	
	16	69.03	.62	1.18	26.62	2.49	.030	*c*
	17	71.08	1.63	1.32	23.56	2.33	.033	*c*
	18	68.23	3.07	1.28	25.05	2.30	.028	*c*
Bearing Bronze	19	78.45	.03	10.02	....	11.44	.041	
	20	77.64	.67	10.06	....	11.56	.037	
	21	77.28	1.57	9.84	....	11.24	.027	
	22	75.14	2.92	10.34	....	11.55	.021	
High-Lead Bearing Bronze	23	67.50	nil	6.21	1.49	24.90	.024	
	24	68.99	.23	7.02	1.13	22.55	.021	*b*, *c*
	25	70.08	.47	7.10	1.30	21.08	.030	*c*
	26	69.90	1.46	7.36	1.18	19.93	.035	*c*
	27	67.86	2.88	6.10	1.02	22.25	.012	*c*

NOTES: *a*—tension test specimens only.
b—compression test specimens only.
c—50 per cent cupro-nickel used in preparation.

25. Pouring temperature has a profound effect upon the properties of many bronzes, and in the present series of tests, castings were secured from a number of different pouring temperatures. The melt was brought to the maximum temperature required, the degree of superheat being controlled by a robust immersion couple operating upon the crucible contents in place in the melting pit.

26. After removal from the pit its temperature was measured with a light-weight, Thwing chromel-alumel immersion couple, and a flask was poured. At appropriate intervals as the pot cooled off, other flasks were poured, the temperature for each being determined with a fresh junction.

27. Generally, tension and compression specimens were cast alternately, the last flask being poured close to or within the freezing range. The result was a series of test specimens distributed over a range of temperatures usually extending to 500 degs. Fahr. above the melting point.

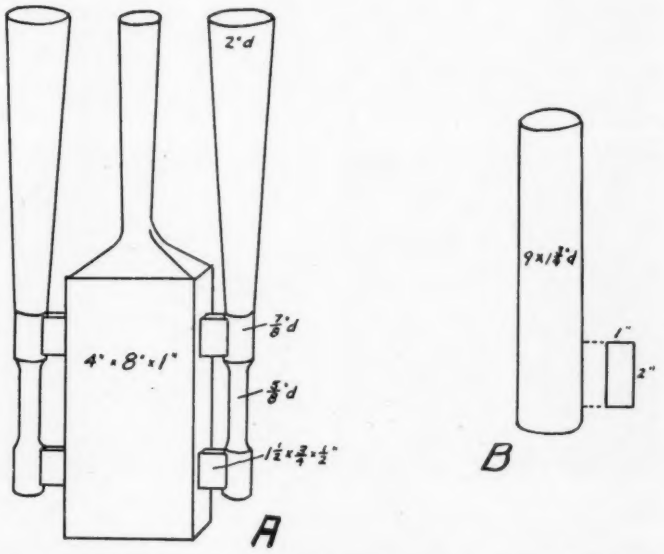

FIG. 1—DIAGRAMMATIC SKETCHES OF TENSION AND COMPRESSION TEST SPECIMENS. *A*: PATTERN FOR TENSION TEST SPECIMEN. *B*: CAST CYLINDER FROM WHICH COMPRESSION TEST SPECIMEN WAS CUT.

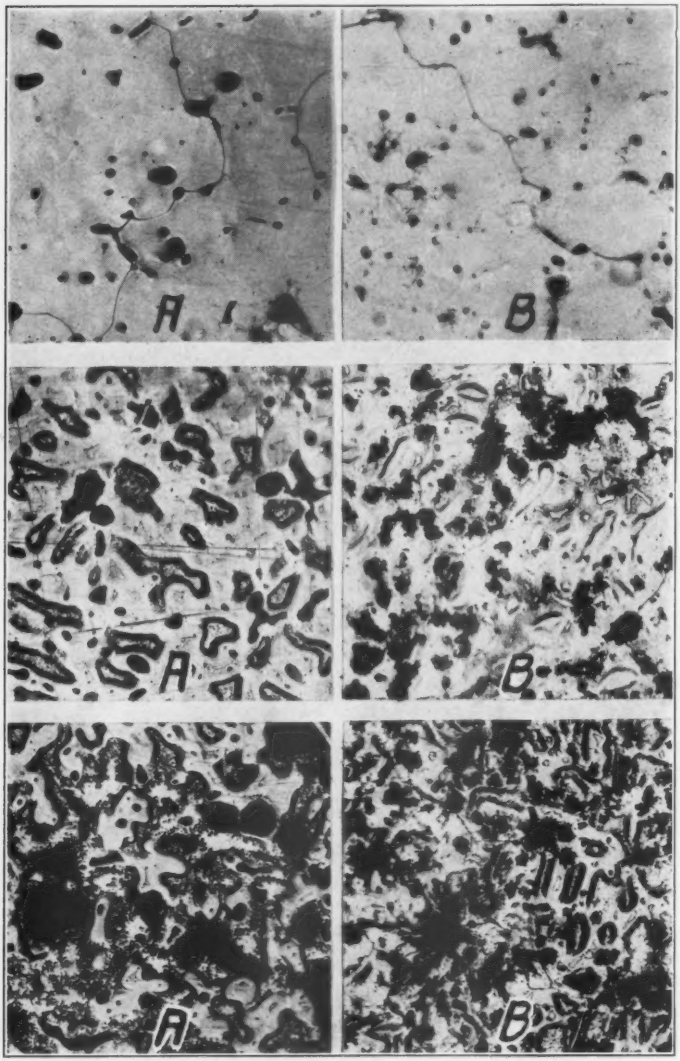

FIG. 2 (TOP)—MICROGRAPH OF YELLOW BRASS, COMPOSITION 70-1-27-2. *A*: 0.03 PER CENT NICKEL ADDED, POURING TEMPERATURE 1935 DEGS. FAHR. *B*: 3.07 NICKEL, POURING TEMPERATURE 1985 DEGS. FAHR. ETCHED, 100X.

FIG. 3 (CENTER)—MICROGRAPH OF BEARING BRONZE, COMP. 80-10-10. *A*: 0.03 PER CENT NICKEL ADDED, POURING TEMPERATURE 2010 DEGS. FAHR. *B*: 2.92 NICKEL, POURING TEMPERATURE 2025 DEGS. FAHR. ETCHED, 100X.

FIG. 4 (BOTTOM)—MICROGRAPH OF HIGH-LEAD BEARING BRONZE, COMP. 72-7-1-20. *A*: NO NICKEL, POURING TEMPERATURE 1935 DEGS. FAHR. *B*: 2.87 PER CENT NICKEL ADDED, POURING TEMPERATURE 1910 DEGS. FAHR. ETCHED, 100X.

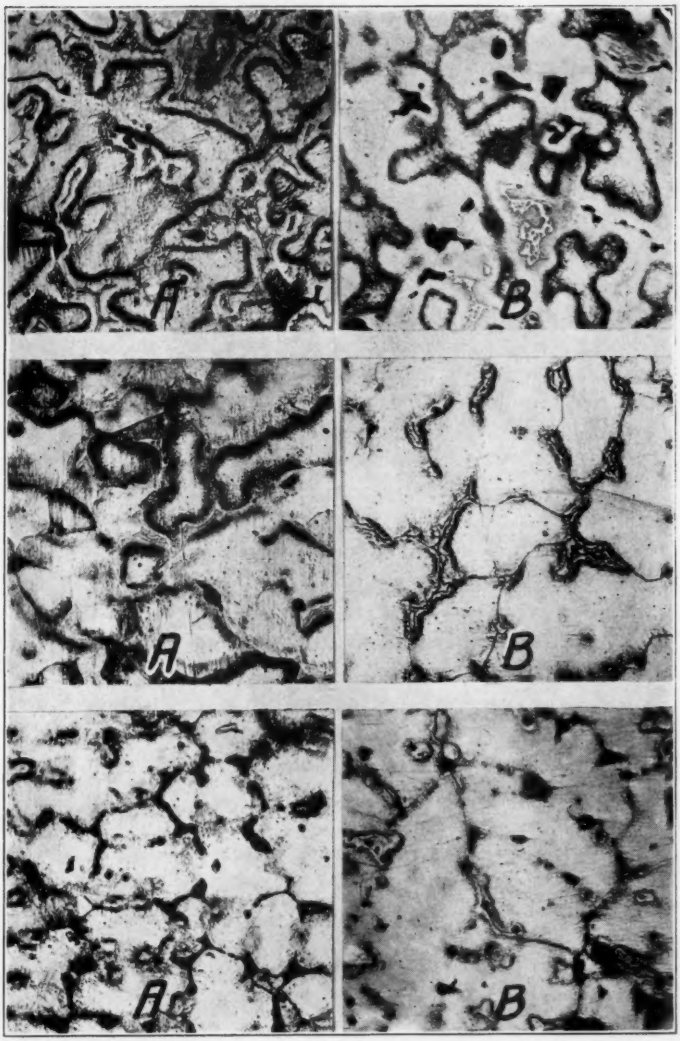

Fig. 5 (Top)—Micrograph of Gear Bronze, Composition 89-11. *A*: Trace of Nickel, Pouring Temperature 2085 Degs. Fahr. *B*: 2.94 Per Cent Nickel Added, Pouring Temperature 2070 Degs. Fahr. Etched, 100X.

Fig. 6 (Center)—Micrograph of G-Bronze, Comp. 88-8-4. *A*: 0.02 Per Cent Nickel Added, Pouring Temperature 2000 Degs. Fahr. *B*: 3.21 Nickel, Pouring Temperature 2025 Degs. Fahr. Etched, 100X.

Fig. 7 (Bottom)—Micrograph of Red Brass, Comp. 85-5-5-5. *A*: 0.03 Per Cent Nickel Added, Pouring Temperature 2080 Degs. Fahr. *B*: 3.03 Nickel. Etched, 100X.

28. The test results are shown in Figs. 8 to 13, inclusive, in which the effect of pouring temperature upon the tensile and compressive properties may be noted. The effect of nickel is brought out more clearly in Figs. 14-19, inclusive, in which the change in a selected group of properties is represented for three different temperatures of pouring.

Gear Bronze.

29. Proportional limits in tension and compression, yield point, ultimate strength and resistance to compression are raised by successive additions of nickel, and it appears that this is accomplished with no loss of ductility up to at least 3 per cent nickel. As would be expected from its high tin content, the mixture is rather sensitive to pouring temperature, and nickel alters this quality to no perceptible degree. The present tests suggest an optimum nickel content of about 2 per cent.

G-Bronze.

30. While the resistance to comparatively slight degrees of deformation, as indicated by proportional limit and yield point, increase continuously with a rise in nickel content up to at least 5 per cent, breaking strength and elongation reach their best proportions at about 1½ per cent nickel content.

Red Brass.

31. This mixture responds excellently to nickel. The strength properties both in tension and in compression rise continuously to beyond 3 per cent nickel, while at the same time ductility is very considerably increased to a maximum at about 2 per cent nickel. The toughness (product of strength $\times$ elongation) of 3 per cent nickel red brass was found to be over twice that of the nickel-free mixture.

Yellow Brass.

32. This mixture is very distinctly improved by nickel contents. Tensile strength, yield point and proportional limit, as well as the compressive strength properties, all rise quite rapidly with increasing contents of nickel, with elongation maintained at a high value. There is no indication that the useful effect of nickel terminates at any low percentage, but the most rapid and

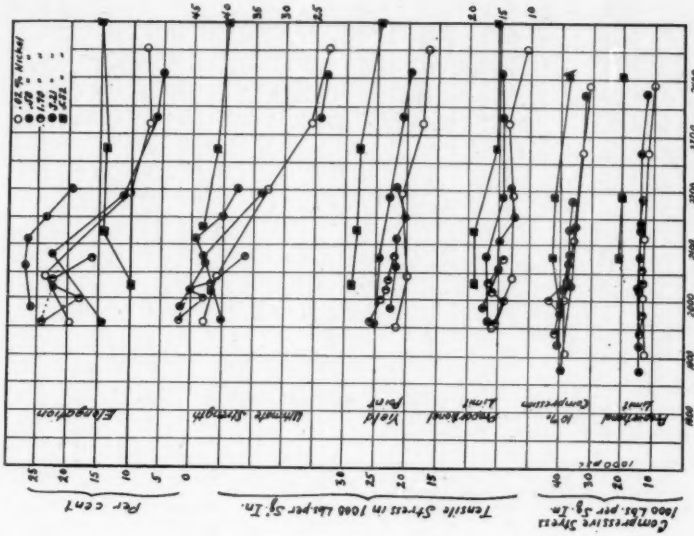

FIG. 8—TEST RESULTS SHOWING EFFECT OF POURING TEMPERATURE UPON TENSILE AND COMPRESSIVE PROPERTIES OF GEAR BRONZE OF COMPOSITION 89-11.

FIG. 9—TEST RESULTS SHOWING EFFECT OF POURING TEMPERATURE UPON TENSILE AND COMPRESSIVE PROPERTIES OF G-BRONZE OF COMPOSITION 88-8-4.

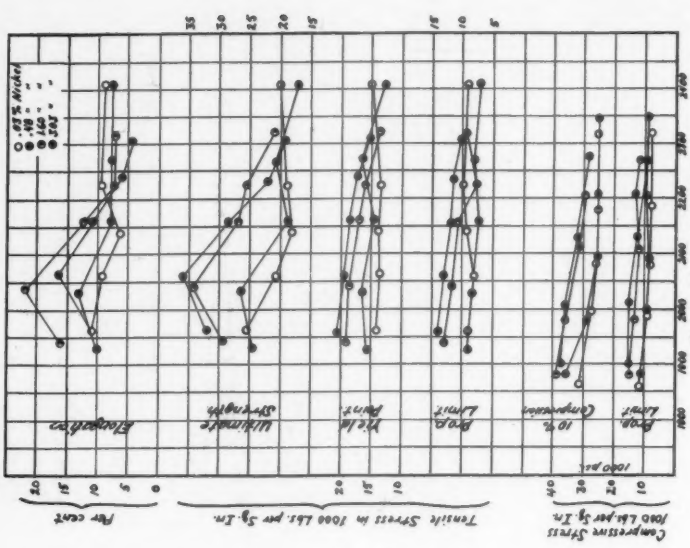
Compressive Strength 1000 Lbs. per Sq. In.
Tensile Strength in 1000 Lbs. per Sq. In.
Per cent Elongation
Pouring Temp., Degs. Fahr.

FIG. 11—TEST RESULTS SHOWING EFFECT OF POURING TEMPERATURE UPON TENSILE AND COMPRESSIVE PROPERTIES OF RED BRASS OF COMPOSITION 85-5-5-5.

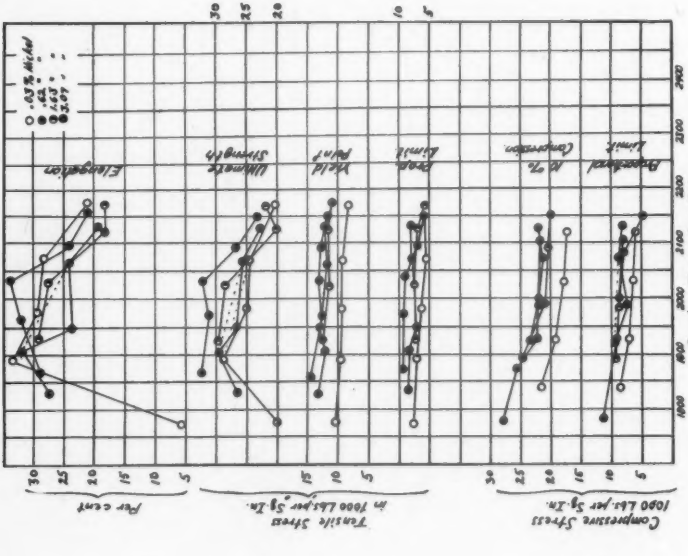
Compressive Strength 1000 Lbs. per Sq. In.
Tensile Strength in 1000 Lbs. per Sq. In.
Per cent Elongation
Pouring Temp., Degs. Fahr.

FIG. 10—TEST RESULTS SHOWING EFFECT OF POURING TEMPERATURE UPON COMPRESSIVE PROPERTIES OF YELLOW BRASS OF COMPOSITION 70-1-27-2.

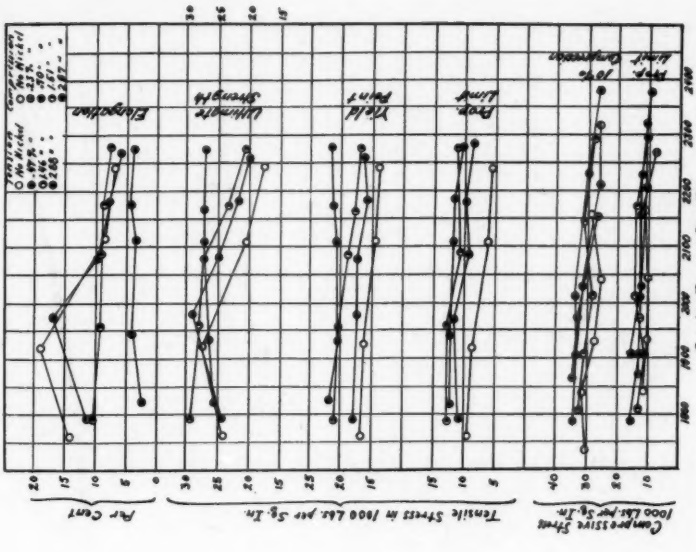

FIG. 13—TEST RESULTS SHOWING EFFECT OF POURING TEMPERATURE UPON TENSILE AND COMPRESSIVE PROPERTIES OF HIGH-LEAD BEARING BRONZE OF COMPOSITION 72-7-1-20.

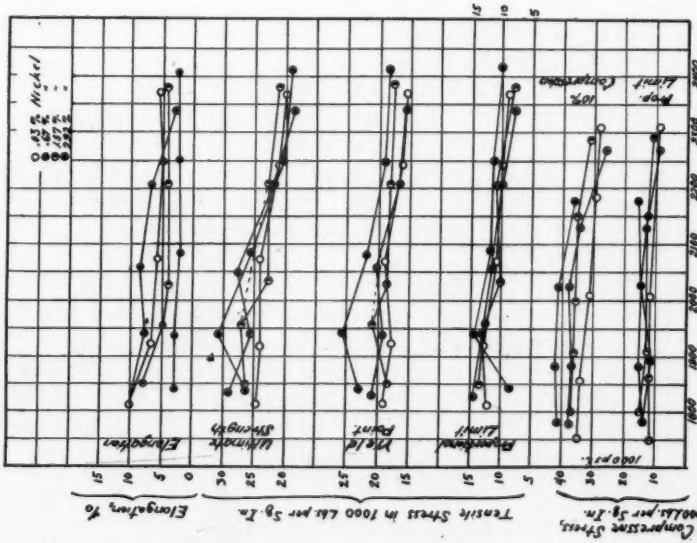

FIG. 12—TEST RESULTS SHOWING EFFECT OF POURING TEMPERATURE UPON TENSILE AND COMPRESSIVE PROPERTIES OF BEARING BRONZE OF COMPOSITION 80-10-10.

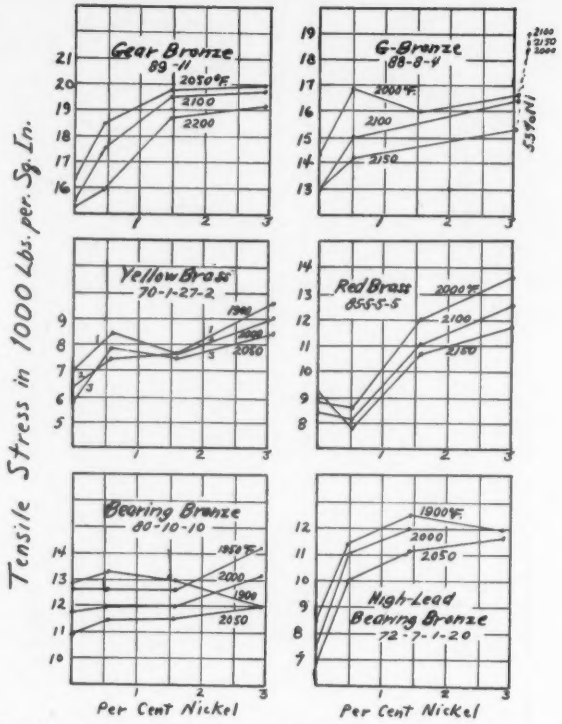

FIG. 14—EFFECT OF NICKEL ON PROPORTIONAL LIMIT IN TENSION, AT VARIOUS POURING TEMPERATURES.

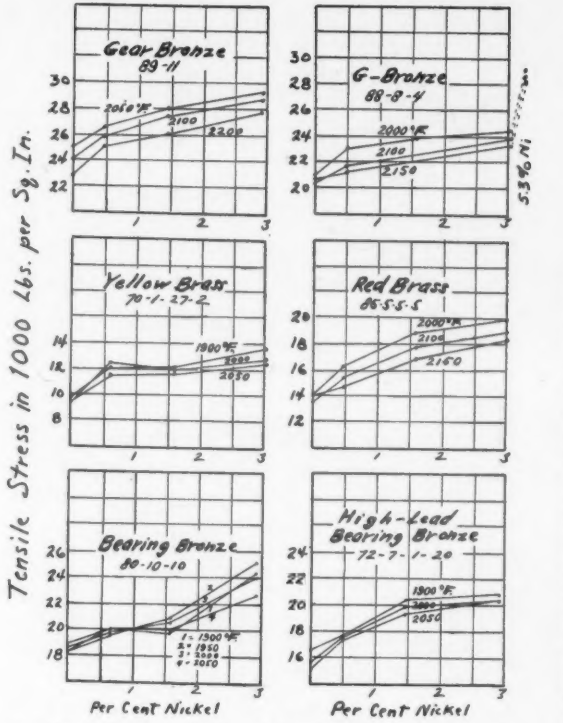

FIG. 15—EFFECT OF NICKEL ON YIELD POINT IN TENSION, AT VARIOUS POURING TEMPERATURES.

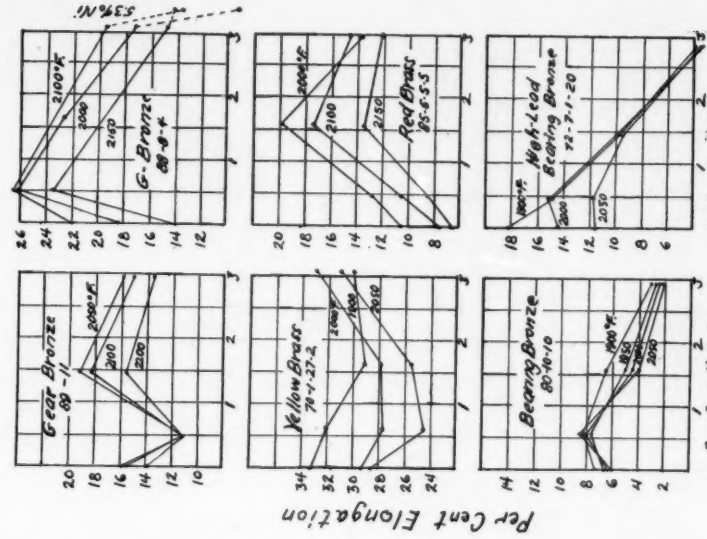

FIG. 17—EFFECT OF NICKEL ON PER CENT ELONGATION, AT VARIOUS POURING TEMPERATURES.

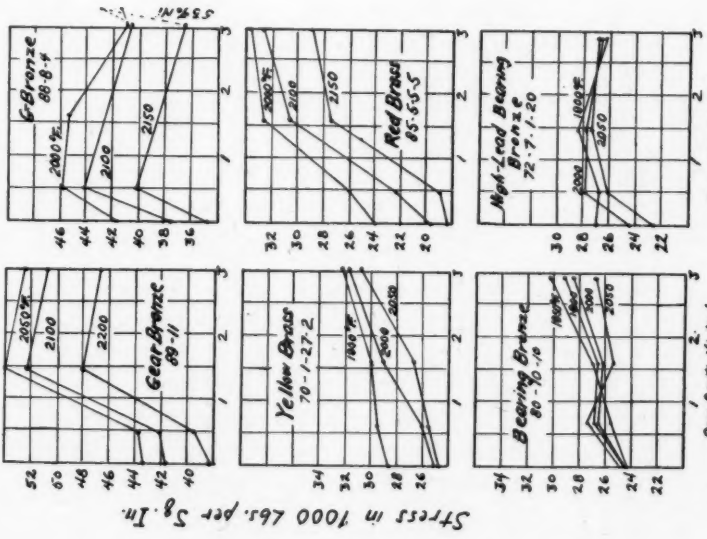

FIG. 16—EFFECT OF NICKEL ON TENSILE STRENGTH, AT VARIOUS POURING TEMPERATURES.

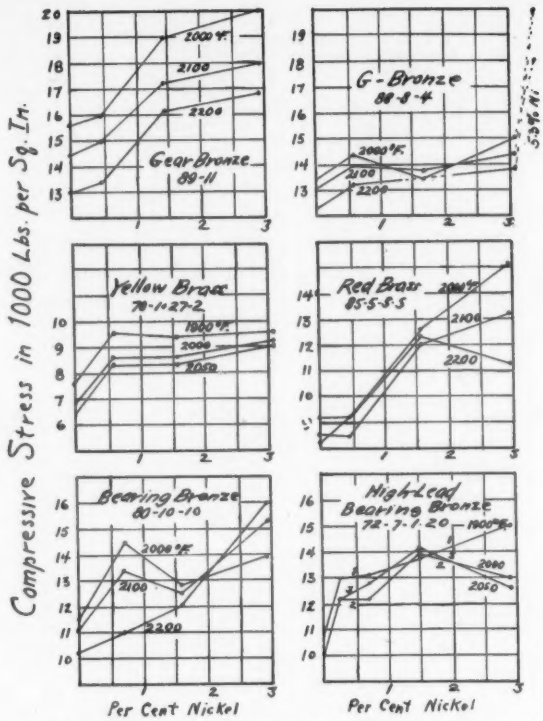

FIG. 18—EFFECT OF NICKEL ON PROPORTIONAL LIMIT IN COMPRESSION, AT VARIOUS POURING TEMPERATURES.

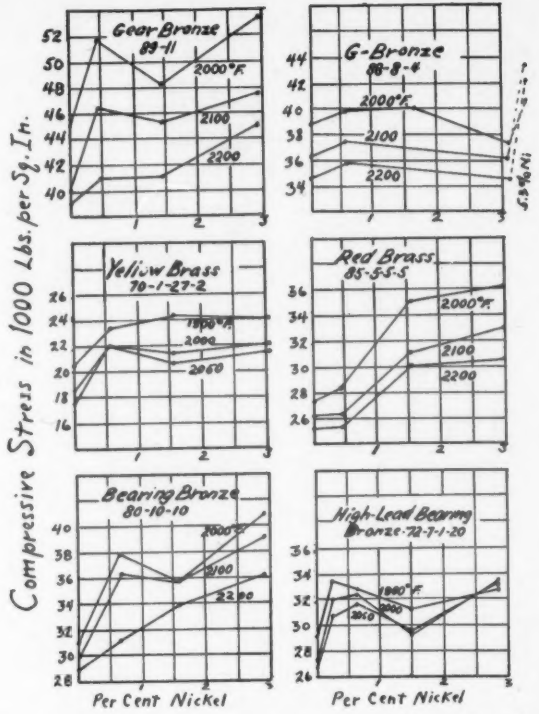

FIG. 19—EFFECT OF NICKEL ON RESISTANCE TO 10 PER CENT COMPRESSION, AT VARIOUS POURING TEMPERATURES.

economically useful improvement in strength occurs with the first per cent of nickel content.

Bearing Bronze.

33. Successive additions of nickel raise the strength characteristics, but a limit is reached at which further increases in nickel diminish the ductility. This limit appears to be about 1½ per cent nickel content.

High-Lead Bearing Bronze.

34. While similar in many respects to the mixture just discussed, this high lead content alloy responds even more quickly to nickel, and its most desirable effect is reached at about 1 per cent nickel content. Higher amounts reduce both elongation and toughness.

CONCLUSIONS

35. Considered in a general way, it appears that the tensile strength, compressive resistance and elastic strength of all six foundry mixtures are improved by small contents of nickel.

36. The best nickel content varies with the nature of the base mixture and, in general, is lower, the higher the tin and/or lead contents; when these last two elements are limited to perhaps one or two per cent each, the advantageous action of nickel in increasing strength and toughness may be extended to contents which are certainly higher than the range considered in this investigation.

37. It seems to be a general characteristic of nickel to increase such properties as proportional limit and yield point to a considerably greater extent than would be expected from the change in tensile strength. In other words, nickel displays its strengthening action most markedly when the deformation involved is small.

38. The importance of this in connection with castings subjected to service of such nature that failure may occur by distortion rather than by fracture is, of course, evident. The extent to which the resistance of sand-cast test specimens to incipient deformation has been increased by appropriate nickel contents is briefly summarized in Table 2.

Table 2

EFFECT OF NICKEL ON RESISTANCE OF TEST SPECIMENS TO INCIPIENT DEFORMATION

Mixture	Ni per cent	Per cent increase in: P L tension	P L Compression	Yield point	10 per cent Compression
Gear Bronze	2	25	25	15	20
G-Bronze	1.5	20	5	10	5
Red Brass	3	40	55	40	30
Yellow Brass	3	40	35	35	40
Bearing Bronze	1.5	5	15	10	15
High Lead Bronze	1	50	30	20	15

39. These changes in strength properties which have been discussed are in part understandable from the microstructural changes which accompany them (Figs. 2-7, inclus.). For a given pouring temperature, bronzes containing the *delta* constituent show somewhat greater amounts of it in the presence of nickel, and the lead-rich constituent of the highly leaded alloys develops an involved surface of contact with the matrix in which it is embedded. It seems probable that nickel also dissolves in and hardens the *alpha* solution.

40. Structurally, both G-bronze and yellow brass are scarcely affected by as much as 3 per cent nickel, although the latter has its strength properties very considerably raised.

DISCUSSION

W. F. GRAHAM:[1] The members of the research laboratory of the International Nickel Co. should be congratulated on presenting the results of such a laborious and extensive investigation of this question. The use of nickel in small quantities in brass and bronze now is becoming extensive. To specification writers, foundrymen and producers of secondary metals, the permissible quantities are rather puzzling, because real information hitherto has not been laid down as to the actual effects.

Commenting on the terminology used by the authors in relation to several alloys, G-bronze, for example, is designated as 88-8-4. For many years "G-bronze" has been the term applied to the alloy 88-10-2, and is so covered by Navy specifications. I do not believe there are many foundries familiar with the term "G-bronze" who would use the alloy

[1]Technical Director, Caskey Brass & Bronze Co., Philadelphia.

88-8-4. They know it as 88-10-2, and it is so designated in the Navy specifications.

Our foundry has made Navy specification work for forty or fifty years, and I know definitely that our men have no knowledge of the composition 88-8-4. The composition 88-8-4 is a new development—a variation. It is covered by A. S. T. M. specifications and also by Navy specification, but I believe it is referred to as a phosphor-bronze in the Navy specification.

The term "bearing bronze" for the composition 80-10-10 is a very good one, but that alloy also is known in many districts as phosphor-bronze, so that the authors' terminology might possibly be confusing. I am not advocating the term "phosphor-bronze" for this alloy, because that would cover other compositions also, but it is known by many as phosphor-bronze.

H. M. ST. JOHN:[2] One of the most interesting characteristics of the small percentage of nickel in these foundry brasses, and certainly one of the hardest to explain, is the effect on fluidity. Nickel being a high-melting-point metal, and in general raising the melting point of alloys to which it is added, it is hard to understand why the pouring temperature of a bronze alloy is reduced by the addition of small quantities of nickel.

We got into a lot of composition ingot some time ago, and we had a great deal of trouble. As a matter of fact, we rejected the ingot, but we were so interested in its behavior that we investigated it further.

We found its outstanding characteristic to be the presence of about 0.5 per cent nickel. We did some work in the laboratory, and when finished we found that we should have kept the ingot.

Later, we investigated the effect of 0.5 per cent nickel in 77-3-10-10 metal, and also in 85-5-5-5. We found, in our particular practice, that the nickel reduced the necessary pouring temperature nearly 100 degs. Fahr. It did not impair the machinability.

We investigated a little further and found that nickel, at least up to 1.5 per cent, did not seem to have any effect upon the machinability one way or another. It did, of course, close the grain very perceptibly in the heavier sections, and that also was a considerable advantage, particularly in castings from which it was necessary to machine off the outside skin.

Rather to our surprise, we found that, in an alloy containing 10 per cent lead, the nickel had no tendency whatever to hold the lead in dispersion. We tried it over and over again, but if we let our tin drop below the critical point, the nickel did not hold the lead.

The advantages in the use of nickel in small quantities in these mixtures proved to be such that we now use it in all of our alloys, 0.5 per cent in the 77-3-10-10, and up to as high as 2 per cent in special alloy which we use for refrigeration work where a very close grain is desired. I cannot speak for yellow brass, but in practically all the red-brass mixtures the use of a small percentage of nickel is a real advantage and apparently has no bad effect.

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[2]Chief Metallurgist, Detroit Lubricator Co., Detroit.

E. R. DARBY:[2] I am very much interested in some of the charted results given in this paper. I notice the form of test bar used by the International Nickel Co. is quite similar to that used by ourselves, excepting that it is cast upright while ours is cast in a horizontal position. I believe the results on the two patterns should be somewhat similar.

On the 85-5-5-5 metal, ordinary red brass, the elongation for 0.03 per cent nickel is given as a maximum of a fraction over 10 per cent. I am quite surprised at this figure. What results have the authors obtained with 85-5-5-5 brass without any nickel?

Again, on the 80-10-10, the authors obtained a maximum elongation in the neighborhood of 10 per cent. We may be all wrong (although I do not think we are), but our maximum elongation on 80-10-10, with the same type of test bar or approximately so, is around 28 per cent without any nickel.

Then, on the high-lead alloy, as shown in Fig. 13, I am surprised at the extent of the elongation obtained. In other words, I am very much interested in these elongation figures and would like to hear further from the authors about them.

T. E. KIHLGREN: With regard to Mr. Darby's question about the 85-5-5-5, that 0.03 per cent nickel is regarded as our "zero" nickel. Any nickel reported as 0.01 or 0.02 per cent is considered to be just a trace of nickel. Most all the analyses reported it as 0.01 per cent.

We realized those values were not as good as the foundryman is getting in regular practice, but I think there are certain factors that should be remembered. One is, that we took care to superheat our metal because we wanted to get well beyond any pouring temperature that would be a useful pouring temperature, for several reasons.

We wanted to see what effect pouring temperature itself had upon these mixtures; we wanted to see if nickel affected the drop in strength with an increase in pouring temperature, and such a thing would make it possible to militate against the best of results, particularly as regards elongation.

In respect to the high-lead alloy in which we had somewhat higher results than Mr. Darby has mentioned, I know of no explanation for it. All that we did was to take care that our charge, whether we had nickel or not, was the same in every case so that our composition would not vary, with the exception of the nickel content.

I believe that reference to our analyses in Table 1 will show that generally our only change has been the change in nickel content, and that in most every case the maximum pouring temperature was about the same, regardless of the nickel content.

I think that the trend due to additions of nickel is quite real, and that, whatever a foundryman's practice may be, if his technique is such that he gets good results, this characteristic of nickel of strengthening the alloy will exist in similar magnitude and he will have continued improvement.

In respect to Mr. Graham's comments, I suppose it would have been

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[2]Chief Metallurgist, Federal Mogul Corp., Detroit.

more correct to have called our G-bronze a "modified" G-bronze, thereby coming closer to the terminology most commonly adopted.

MEMBER: Has the International Nickel Co. made any tests with the additions of nickel to the 60-40 range, such as manganese-bronze, or Naval brass, or aluminum-bronze?

T. E. KIHLGREN: We have only had the opportunity to investigate these six mixtures that we felt covered the copper-zinc-tin-lead range. That is, we did not refer to the special bronzes at all.

WRITTEN REPLY BY AUTHOR

N. B. PILLING: In further reply to the points which Mr. Darby has raised, it seems to us that two factors contribute to the circumstance he notes regarding differences in elongation and strength between some of these experimentally prepared alloys and similar ones in commercial production. Our mixtures were all necessarily made from new metals, in order to insure the proper composition control required by the purpose of the tests. It is commonly appreciated that remelting, such as usually occurs in continuous production, frequently results in an improvement in these qualities.

Table 3

TENSILE PROPERTIES OF 85-5-5-5 CONTAINING 0.01 PER CENT PHOSPHORUS MAXIMUM, AS AFFECTED BY NICKEL.

	Nickel Content, Per Cent			
	0	0.5	1.5	3.0
Proportional Limit, lbs. per sq. in.	8,900	10,000	11,500	12,100
Yield Point, lbs. per sq. in.	16,000	17,000	18,100	18,600
Ultimate, lbs. per sq. in.	27,000	26,100	29,000	33,000
Elongation, per cent in 2 in.	15.0	12.2	13.7	18.5

Again, it is perhaps the case that the phosphorus content of about 0.05 per cent was higher than desirable for the development of an optimum combination of properties in certain of the mixtures. In the case of 85-5-5-5, information which we have suggests this to be so.

The data given in Table 3 relate to this mixture, prepared also from new metals, such that the residual phosphorus content was less than 0.01 per cent. For purposes of comparison with the data given in the paper,

it may be noted that the test specimens in Table 3 were cast at a temperature of 2120 degs. Fahr.

It seems clear, therefore, that improvements in strength properties brought about by refinements in production technique, do not disturb the general relations regarding nickel which have been developed.

Cupola High-Test and Alloy Irons in a Machine Tool and Gray Iron Jobbing Foundry

By L. M. Sherwin* and T. F. Kiley,** Providence, R. I.

Abstract

This paper deals with cupola practice, mixture and materials used in manufacturing a low-carbon (2.75-3.00 per cent) iron, commonly referred to as high-test cast iron and used on certain classes of work with success by the author's firm. Methods of control, typical analyses of resulting product and microstructures are discussed and comparisons made between machining, strengths and other physical characteristics of this and other iron mixtures regularly used. The production of sound castings of difficult design is stressed more than high strength, although the latter generally follows with such irons. Problems involved in pouring, feeding and gating are more difficult than those encountered with usual grades of iron. Special dry-sand mixtures apparently are necessary to obtain a sound, smooth-surface casting on medium and heavy work. Castings illustrated and poured successfully with high-test iron include those which have been found very difficult to get sound from mixtures containing up to 30 per cent steel, even with low silicon content, without resorting to chills; castings of such design as to favor a draw between thin and adjoining heavy sections; heavy sectioned castings requiring absolute soundness when machined deeply; castings used in hydraulic work or where subject to high pressures; castings where high strength or exceptional wearing qualities are demanded. Cost of castings made from high-test iron is more than with regular grades of iron, due in most cases to dry-sand molding, increased supervision, more coke, larger foundry returns and use of best molders. Effect of molybdenum on low-carbon iron and regular 20 per cent

*Foundry and Pattern Shop Superintendent, Brown & Sharpe Mfg. Co.
**Foundry Metallurgist, Brown & Sharpe Mfg. Co.

steel mixture is described, also nickel as an aid in machining when using mixture of iron suitable for castings of difficult design or in securing casting with better wearing qualities, also chromium-treated irons for castings subject to heat or great wear. The decision whether to use high-test or alloy iron, rather than chill and green sand, is decided in preliminary investigation, the ultimate cost being the deciding factor where either method will result in a satisfactory casting. The authors consider high-test and alloy irons a valuable aid in meeting special needs of customer and in production of quality castings where design is difficult.

1. During the past few years many papers and much research data have been published on the subject of high-test and alloy cast irons, both in this country and abroad. Investigations along these lines have done much, we believe, to clarify and improve that complex material known as cast iron.

2. It is beyond the scope of this paper to review what has been done on this subject. Anyone interested in this phase can readily obtain such data by reading over past *Transactions* of the A. F. A., or articles published in the technical press.

3. The pioneers in the study of these irons and in research and practical work in this connection are to be congratulated for their splendid work and courage, for a few years ago it required the highest type of courage even to consider melting up to 95 per cent steel in a foundry cupola. At the present time many good foundrymen are far from being sold on the idea.

4. There are foundries that have benefited in a very practical way by the application of the data brought out in these papers. Others are engaged in a class of work where there is no practical use for this type iron. Also, others, after making a few experiments, have abandoned further attempts as being highly impractical.

5. High-test and alloy irons are, we believe, a real aid to the gray iron industry and well worth the study and trial of the foundryman who sometimes is driven to his wits end to produce a sound casting. Customers often have been driven to substituting other material because of the lack of quality in their gray iron castings. There is more than one type of gray iron. There are an infinitesimal number, some having the qualities that the customer wants and for which he is willing to pay.

6. The time has come when we must study more carefully the requirements of the customer, give him the quality he desires and educate him to pay a fair price for a superior material. This attitude will do much in bringing the gray iron industry again into its own.

Helps Maintain High Standard

7. The firm with which the authors are associated conduct a foundry for the production of their own machine-tool castings, and also do a large jobbing business. The standards are high, and high standards mean higher costs, so that ordinarily we do not get the simpler work. Very often the work we get is something some other fellow has had trouble with and often we have our own share of trouble before overcoming the difficulty. High-test and alloy irons have been of invaluable aid in solving some troubles that otherwise could have been solved only with great difficulty and loss.

8. Melting large percentages of steel in the cupola in the production of high-test iron, pouring the product into molds and obtaining a superior casting for certain classes of work, is a problem alive with many chances to go wrong on some particular phase, with resulting loss. Consequently, very strict attention must be paid to details—an exact procedure must be worked out and carefully followed.

9. The procedure outlined in this discussion is the culmination of a great deal of practical foundry research carried on over a period of three years before this material obtained its present status and gave us consistently good castings. We present this data with the hope that others may find something of profit in our experience with it. We make no claims that this is the best practice, but it is at least one way of doing it. Only by unreserved information and interchange of ideas can we progress.

Sound Castings Main Consideration

10. It may be stated here that our main interest in high-test cast iron has been in the production of a sound casting—high strength, which generally follows, is in most of our cases a secondary consideration. For the major portion of our castings and outside work, some one of our regular iron mixtures will produce a satisfactory casting.

11. Frequently, however, a job comes in for an outside customer, or a difficult design for our own shop, requiring the use of alloy or high test iron. These include castings which have been found very difficult to get sound from regular mixtures containing up to 30 per cent steel, even with low silicon content, without resorting to chills; castings of such design as to favor a draw between thin and adjoining heavy sections; heavy sectioned castings requiring absolute soundness when machined deeply; castings used in hydraulic work, subject to high pressures, or castings where high strength or exceptional wearing qualities are demanded.

12. Very obstinate cases of internal shrinkage, sponginess and porosity almost invariably can be eliminated by use of low-carbon cast iron, and often this offers the only solution unless it is possible to stop the trouble by the use of chills or feeders. Sometimes chills are the cheapest way out, particularly if the casting has sections less than ¼ in., or if the section causing the trouble is easy to chill.

13. Chills, however, are expensive and always present a hazard in the mold, due to their tendency to collect moisture and cause a blow. During our preliminary work on high-test cast iron, many castings were tried which were chilled to get soundness with regular iron mixtures, but which, when tried in high-test iron, invariably were sound without chills.

PRELIMINARY INVESTIGATION ON PATTERNS

14. On arriving at the foundry, patterns are carefully examined. If the design seems to be difficult, before proceeding with the order experimental castings are made up from a mixture considered most suitable, and castings are sawed on a power hacksaw at locations where there is a tendency to have a shrink. If castings are too large to do this, they are sent to the shop and partly machined before proceeding. In this way the accumulation of a large percentage of defectives in the machine shop—a loss both to our firm and to the customer—often is prevented.

CUPOLA PRACTICE ON HIGH-TEST IRON

15. Melting is performed in the same cupola used daily for our regular iron mixtures. This is lined to 54 inches, with a

tuyere to cross-sectional area of 1:5. Air is supplied by a turbine blower delivering 6500 cu. ft. per minute per gage at a pressure of 12 to 15 ounces.

16. An initial high coke bed is carried 60 inches above top of tuyeres. The bed is ignited with an oil burner through the breast. When the flames start to break through the bed, the oil burner is removed and the blast is put on for a few minutes until the bed is brought to an incandescent red all over the top. Charging then is started at once.

17. Ton charges and hand charging are used throughout the heat. About 100 lbs. of a good grade of limestone and 6 lbs. of alkali flux are thrown in on the bed. High test returns then are scattered all over the bed. Half of the steel charge comes next, leaving a depression in center for the ferroalloys. Ferroalloys then follow, and finally the remainder of the steel, completely covering the ferroalloys.

18. As a general rule, not over one to two tons of high-test cast iron are run, and this is always charged first. Three hundred pounds foundry coke are used between ton charges. The cupola then is filled to the door with other grades of iron and allowed to stand for one to two hours before putting on the blast.

19. The blazing of the bed and the pre-heat aids, we believe, in preventing a frozen tap hole, and insures very hot iron from the start. A breast brick with ⅞-in. diameter hole is used and the stream is practically continuous on opening the tap hole, except when raising the level of metal for slagging.

How Iron Is Delivered

20. The iron runs into a 1,000-lb. receiver ladle which delivers iron to ladles on a monorail, which in turn delivers iron to the molders in the light foundry for shanking off, or a receiver ladle delivers to a lift-truck ladle for pouring off heavier work.

21. All ladles are heated well with charcoal fire before pouring iron into them. The tap hole is opened 20 minutes after the blast is put on. The first few hundred pounds of this iron is pigged to warm up the ladles. An extra 1,000 lbs. over requirements of high-test iron is allowed for warming up ladles and to insure against getting too close to other grades of iron in the stack.

Table 1

MATERIALS AND ORDER OF CHARGE, AND ANALYSIS OF MATERIALS OF CHARGE

Materials of Charge

Materials charged.	Quantity, lbs.	Per cent of total charge.
Steel rails, truck tire rims, or cold rolled factory steel (none very light nor very heavy)	1500	75.0
High-test returns	390	19.5
Silico-manganese (lump)	25	1.25
Ferrosilicon (lump)	85	4.25

Order of Charging

(1) High-test returns
(2) Half steel
(3) Ferroalloys
(4) Half steel

Analysis of Materials of Charge

STEEL:

Used to following specifications:

Carbon.....0.60 maximum
Section.....¼ in. to 1 in. thickness
Weight.....not to exceed 30 lbs.
Length..... 18 in. maximum

No small clippings, punchings or similar stock. Steel must be clean and free from scaly rust.

LIMESTONE OR DOLOMITE:

Sum of iron oxide (Fe_2O_3) plus aluminum oxide (Al_2O_3) plus silica ($Si\ O_2$) not to exceed 3 per cent.

COKE:

Used to following specifications:

Moisture ..... 2.00 per cent maximum
Sulphur ..... 1.00 per cent maximum
Ash .....10.00 per cent maximum
Volatile ..... 2.00 per cent maximum
Fixed Carbon .....85.00 per cent minimum

Typical Approximate Analysis

Sulphur ..... 0.75 per cent
Volatile ..... 1.00 per cent
Ash ..... 8.00 per cent
Moisture ..... 0.50 per cent
Fixed carbon .....90.50 per cent

SILICO-MANGANESE:

Manganese .....65 to 70 per cent
Silicon .....20 to 25 per cent

FERROSILICON:

Silicon .....50 per cent

22. The mixture following the high test iron is one containing 30 per cent steel. The steel is charged first, so there is very little trouble with getting a higher carbon due to contamination from higher carbon mixtures. Readings taken with an optical pyrometer shortly after opening the tap hole show about 2800 degs. Fahr.

23. Table 1 gives the data on the materials of the charges when high-test return scrap is available. Table 2 gives the data on the charges when high-test returns are not available.

Table 2

Mixture Used When High-Test Returns Not Available

Materials charged.	Quantity. lbs.	Per cent of total charge.
Steel	1500	75.0
Ferromanganese (lump 80% Mn)	30	1.5
Ferrosilicon (lump 50% Si)	70	3.5
High Silicon Pig: Si 14.45%; S 0.16; Mn 0.15; P 0.12; TC 1.39	140	7.0
High Manganese Pig: Si 2.78%; S 0.025; Mn 2.16; P 0.22; TC 3.80	260	13.0

Pouring

24. High-test iron for medium castings is distributed to the molders rapidly by monorail. Hand ladles are well dried and heated with molten iron before using. Iron must be poured just as hot as possible (about 2600 degs. Fahr.), as the rapid setting nature of this type iron will not permit dull pouring.

25. Molders not accustomed to such irons are inclined to allow it to slack down before pouring, with disastrous results. A large enough pouring crew must be used to empty a 300-lb. tram ladle rapidly. Heavier work need not be handled so fast, nor poured quite as hot.

Molding and Gating

26. Iron must be poured into molds for medium work just as rapidly as possible. The gates are, in general, about half again as thick as those ordinarily used with a 20 per cent steel mixture. Medium castings often are poured two up to get iron into the

Table 3

SAND MIXTURES USED FOR MEDIUM WORK

Oil Facing Sand:
130 quarts Providence fine sand (dried)
90 quarts No. 00 Albany molding sand (dried)
50 quarts silica flour
10 quarts linseed oil
Glutrin Backing Sand:
150 quarts used and crushed glutrin backing and oil facing sand
120 quarts New England silica sand (Provincetown)
7 quarts glutrin

mold fast enough. Basins are kept well choked and risers and strainer gates resorted to, to insure an absence of slag in castings.

27. Heavy sections must have ample risers at the high point; with this iron, external liquid shrinkage is greater than with usual grades, and depressions are likely to occur unless fed back. The risers often are fed back with hot iron, but they must be large enough to set later than the casting adjacent to it, otherwise the riser will draw from the casting, leaving a spongy spot. Molding, gating and pouring must be of a high grade to insure success in casting.

SAND USED

28. The action of this metal on green-sand molds for medium and heavy work is very severe, resulting in very rough surfaces, cuts, scabs and washes, which indicates that green sand does not withstand this iron on this class of work. Green sand also results in a large percentage of castings showing slag inclusions and gas holes after machining. This is probably due to

Table 4

PHYSICAL CHARACTERISTICS OF SAND MIXTURES USED FOR MEDIUM WORK

Oil Facing Sand:	
*Green bond	2½ to 3 lbs.
*Dry bond	25 to 35 lbs.
*Dry permeability	90 to 150
Glutrin Backing Sand:	
*Green bond	1¼ to 1¾ lbs.
*Dry bond	25 to 35 lbs.
*Dry permeability	700 to 1200

*Testing equipment used was developed by H. F. Campbell, Univeristy of Michigan, Ann Arbor, Mich.

necessary moisture in the green sand, which further hastens the setting of an already fast-setting metal and prevents the elimination of gas and slag from the metal.

29. After trying various means to overcome this trouble by use of sea-coal facing, by steel molding sands, and by blacking heavily the surface of molds, green sand had to be abandoned in favor of dry-sand molds on the medium work. The molds are faced with a very fine oil-sand mixture and backed with a very open glutrin-bonded sand. The used sand in glutrin backing sand is taken from crushed dry-sand molds after shakeout. Sand mixtures are given in Tables 3, 4 and 5.

Table 5

Screen Tests on Sands Used in Mixtures for Medium Work

No. 00 ALBANY MOLDING SAND

Sieve No.	Per Cent
On 6	0.00
12	0.00
20	0.20
30	0.10
40	0.10
50	0.22
70	0.66
100	2.18
140	6.28
200	19.20
270	8.66
Pass 270	50.14
Clay substance	12.24
Total	99.98
Grain fineness	231
Green bond compression at 8% H_2O	4.5 lbs.
Green permeability at 8% H_2O	10.0

A. F. A. Classification:
Grain—Class No. 1.
Clay—Class E.

PROVIDENCE FINE SAND

Sieve No.	Per Cent
On 6	0.00
12	0.14
20	1.00
30	0.84
40	1.26
50	8.60
70	19.78
100	22.70
140	25.18
200	13.40
270	1.20
Pass 270	5.50
Clay substance	0.38
Total	99.98
Grain fineness	100
Green bond compression at 5% H_2O	0.9 lbs.
Green permeability at 5% H_2O	105.0

A. F. A. Classification:
Grain—Class No. 3.
Clay—Class A.

CRUSHED DRY-SAND MOLDS

Sieve No.	Per Cent
On 6	0.19
12	1.14
20	6.32
30	14.79
40	16.32
50	10.20
70	13.19
100	15.39
140	4.35
200	7.09
270	3.27
Pass 270	5.22
Clay substance	2.57
Total	100.04
Grain fineness	68

A. F. A. Classification:
Grain—Class No. 5.
Clay—Class C.

NEW ENGLAND SILICA—PROVINCETOWN

Sieve No.	Per Cent
On 6	0.00
12	0.00
20	4.78
30	0.00
40	68.96
50	0.00
70	25.48
100	0.34
140	0.14
200	0.06
270	0.02
Pass 270	0.92
Clay substance	0.18
Total	99.98
Grain fineness	25
Green bond	Nil
Permeability	2000

A. F. A. Classification:
Grain—Class No. 8.
Clay—Class A.

Table 6

PHYSICAL CHARACTERISTICS OF SAND MIXTURES FOR HEAVY WORK

FLOUR FACING	
Moisture, per cent	6.0
Green permeability	50 to 80
Dry permeability	300 to 400
Green bond (compression), lbs. per sq. in.	4.5
Dry bond (compression 1-in. cube), lbs.	18
SANDSLINGER HEAP	
Green permeability at 7% H_2O	31.0
Green bond (compression) at 7% H_2O	4.6 lbs.

30. Table 3 gives the mixture for the oil-facing sand and glutrin backing sand for medium work, while Table 4 outlines the typical characteristics of these sands. In Table 5 are reproduced the screen tests on the materials used in sand mixtures for medium work. Of the silica flour, which is not described in this table, 98 per cent passes the 200-mesh screen.

BAKING PRACTICE

31. Dry-sand molds for medium work are baked overnight at a temperature of 425 degs. Fahr.

SAND MIXTURES FOR HEAVY WORK

32. Lacking facilities for baking the molds for heavier work, a flour-bonded facing sand generally is used with backing

Table 7

SCREEN TESTS ON SANDS USED IN MIXTURES FOR HEAVY WORK

FLOUR FACING—MILLVILLE MOLDING

Sieve No.	Per Cent
On 6	3.01
12	3.08
20	11.03
40	22.44
70	26.47
100	10.39
140	3.31
200	.91
270	.46
Pass 270	1.10
Clay substance	17.80
Total	100.00
Grain fineness	47
Bond compression at 8% H_2O	8.5 lbs.
Permeability at 8% H_2O	156

A. F. A. Classification:
Grain—Class No. 6.
Clay—Class F.

SANDSLINGER HEAP

Sieve No.	Per Cent
On 6	.24
12	.97
20	4.68
30	8.75
40	9.62
50	7.67
70	11.12
100	13.43
140	3.06
200	10.33
270	5.23
Pass 270	13.45
Clay substance	11.22
Total	99.77
Grain fineness	103

A. F. A. Classification:
Grain—Class No. 3.
Clay—Class E.

of green sand from our sandslinger heap. Molds are sprayed with the following mixture:

24	quarts	plumbago
2	"	bentonite
2	"	molasses
24	"	water

33. Molds then are well skin dried with an oil torch. If precautions are taken to torch the mold shortly before casting, fairly good results are obtained by this method, although baked molds are preferred when possible. Sand mixtures used are as follows:

Flour Facing

150	quarts	sandslinger heap sand
70	"	Millville molding sand
70	"	New England silica sand (Provincetown)
10	"	flour

34. The physical characteristics of sand mixtures for heavy work are given in Tables 6 and 7.

ROUTINE TESTS ON IRON MIXTURES

35. In order to compare some of the characteristics of high-test iron with usual grades of iron mixtures, we are describing tests and other iron mixtures run in this foundry. In Fig. 1, *A* shows test bars 1 in. square by 13 in. long which are used for routine tests. They are cast flat in green sand, two in a flask and gated on end. Tests made on these bars daily are described in paragraphs 36 to 41, inclusive, below.

Transverse.

36. Plain bar without projections is tested on Riehle transverse machine, 12 in. between supports, and record is made of transverse breaking load and deflection. Occasionally, tests are made on arbitration bar, A. S. T. M. standard, 18 in. between supports.

Pattern-Makers' Shrinkage (solid contraction).

37. Bar made from pattern with projections 12 in. apart. The distance between projections is measured after casting, and shrinkage is recorded.

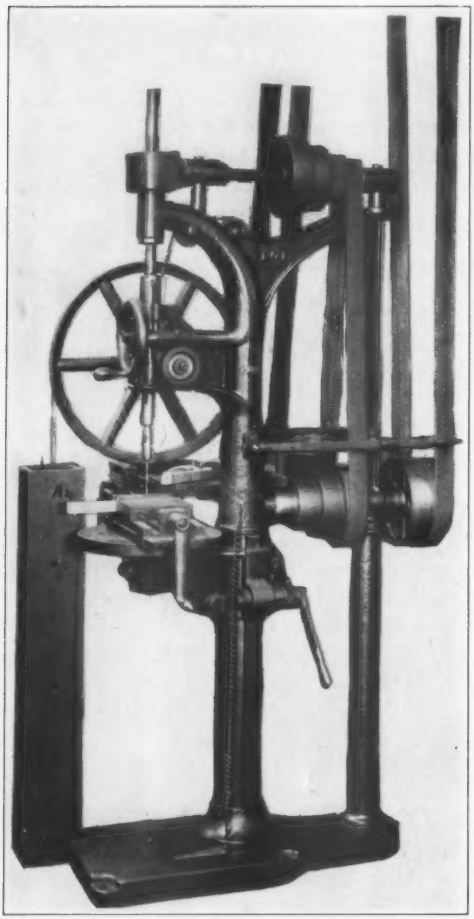

FIG. 1—HIGH-SPEED DRILL PRESS FOR DRILLING TEST BARS FROM VARIOUS MIXTURES, WITH TEST BAR (*A*) IN PLACE FOR DRILLING. (SEE PARAGRAPHS 35, 39, 40.)

Brinell.

38. Plain bar is cut off 3 in. from end opposite gate, and Brinell is recorded at the center of cross-section.

Drill Test.

39. Test bars from each of various mixtures are drilled with a ¼ in. high-speed drill by means of a special drill press (shown in Fig. 1). This is equipped with a weight of 12 lbs., attached to a pulley, and guides which show when drill has penetrated to a depth of ¾ in. The time to drill a standard bar is noted in seconds; then the time is noted for drilling a test bar from the various mixtures at the same location. The increase or decrease in time then is recorded in percentage, plus or minus.

40. Inasmuch as the standard bar was in the first place taken from one of our regular mixtures (Mixture No. 3, Table 8), occasionally a bar is tested which drills in exactly the same time as the standard. Such bars are laid aside and held for future standards. The use of a standard for checking purposes offsets variables in the belt, sharpness of drill power, etc. The following examples may explain this more clearly.

Time to drill standard, seconds	Time to drill test bars, seconds	Difference, seconds	Percentage
27.6	29.8	+2.2	+ 7.8
27.6	20.2	—7.4	—26.8

41. In the first example, the sample is 7.8 per cent less machinable than standard; in the second example, the sample is 26.8 per cent more machinable than standard.

42. Table 8 gives the standards for mixtures, analyses and physical characteristics of regular iron mixtures, some one of which is suitable for the large majority of patterns entering the foundry.

Structure of High-Test Irons

43. A study of the characteristics of high-test and regular iron mixtures recorded in Tables 8, 9, 10 and 11, and a study of microstructures, suggest the conclusions in paragraphs 44 to 52, inclusive.

44. The higher the combined carbon in high-test iron up to the eutectoid, the higher is the transverse and tensile strength.

Table 8

STANDARDS FOR REGULAR MIXTURES

Mixture No.	Mixture	1-in. Square Bar										A. S. T. M. Bar			Type of Casting
		Si	S	Mn	P	T C	C C	Transverse, lbs.	Deflection, inches	Brinell	Shrinkage, inches	Drill	Transverse, lbs.	Deflection, inches	Tensile strength, lbs. per sq. in.	
1	30% Steel... 20% Returns 50% Pig.....	1.80	.10	.60	.20	3.20	.65	3,300	.14	196	.13	+5.0%	1,900	.25	33,000	Used on fairly heavy work where close grain and strength is essential Min. section ½ in.
		2.00	.14	.90	.30	3.40	.80	3,600	.18	217	.15	+15.0%	2,300	.27	40,000	
2	5% Steel... 45% Returns 50% Pig.....	1.90	.08	.50	.30	3.40	.50	2,800	.15	187	.10	0.0%	1,900	.25	30,000	Used on regular run of side floor work.
		2.10	.11	.70	.50	3.60	.70	3,300	.18	207	.14	—10.0%	2,200	.28	35,000	
3	20% Steel... 30% Returns 50% Pig.....	1.90	.09	.60	.20	3.20	.60	3,200	.14	187	.12	+5.0%	2,000	.25	35,000	Used on heavy bench, machine and floor work requiring close grain and strength Min. section ¼ in.
		2.20	.12	.80	.30	3.50	.75	3,500	.17	207	.14	— 5.0%	2,400	.28	39,000	
4	50% Returns 50% Pig.....	2.00	.08	.50	.40	3.45	.40	2,800	.15	156	.10	—10.0%	1,600	.25	24,000	Used on regular run of light work. Min. section ⅛ in.
		2.40	.10	.60	.60	3.65	.60	3,200	.18	179	.13	—30.0%	2,000	29	30,000	

Table 9

HEATS OF REGULAR IRON MIXTURES

Mixture No.	Mixture	1-in. Square Bar—Green Sand: Si	S	Mn	P	T C	C C	Transverse, lbs.	Deflection, inches	Brinell	Shrinkage, inches	Drill	A. S. T. M. Bar: Transverse, lbs.	Deflection, inches	Tensile strength, lbs. per sq. in.	Half Way to Center of Tensile Piece: Fig. No
1	30% Steel ... 20% Returns 50% Pig	1.82	.140	.58	.27	3.25	.79	3,283	.14	207	.150	+8.2%	2,049	.26	39,400	2-*A* 6-*A*
2	5% Steel .... 45% Returns 50% Pig	1.90	.087	.61	.45	3.45	.59	3,374	.16	187	.125	−9.2%	1,952	.28	34,900	2-*B* 6-*B*
3	20% Steel ... 30% Returns 50% Pig	2.08	.100	.72	.28	3.22	.66	3,411	.13	196	.140	+0.7%	2,018	.25	38,950	2-*C* 7-*A*
4	50% Returns 50% Pig....	2.11	.082	.62	.38	3.56	.55	2,992	.18	163	.120	−20.0%	1,691	.29	25,000	3-*A* 7-*B*

NOTE: The above table is a record of a heat of each one of regular iron mixtures which is representative, and is given for the purpose of making a detailed study of the characteristics of actual heats of regular mixtures as compared to heats of high-test irons.

Table 10

STANDARD PLAIN HIGH-TEST IRON

Heat No.	Mixture	1-in. Square Bar: Si	S	Mn	P	T C	C C	Transverse, lbs.	Deflection, inches	Brinell	Shrinkage, inches	Drill	A. S. T. M. Bar: Transverse, lbs.	Deflection, inches	Tensile strength, lbs. per sq. in.	Fig. No.
A	75% Steel, 1¼% Fe.-Mn, 3½% Fe.-Si, 13% High Mn. Pig, 7% High Si. Pig	2.66	.114	1.05	.14	2.86	.63	3,298	.14	241	.163	+29.0%	2,216	.23	41,200	.....
B	Same	2.31	.158	.94	.10	2.98	.82	4,000	.15	269	.150	+24.1%	2,477	.25	41,800	.....
C	Same	2.19	.103	.92	.10	2.99	.78	3,891	.15	228	.145	+22.1%	2,268	.21	45,600	.....
D	Same	2.17	.169	1.01	.09	2.92	.82	3,874	.15	241	.155	+31.2%	2,400	.24	45,000	.....
E	Same	2.73	.148	1.06	.07	2.84	.76	3,800	.14	241	.155	+36.5%	2,305	.24	44,900	.....
F	Same	2.85	.131	1.29	.10	2.96	.72	3,648	.13	241	.150	+32.6%	2,343	.27	42,150	.....
G	Same	2.77	.137	1.10	.092	3.05	.71	3,746	.15	228	.140	+34.3%	2,115	.25	41,600	.....
H	Same	2.71	.152	.79	.07	2.80	.86	4,000	.15	255	.165	+39.6%	2,402	.22	50,700	3-*B* and 8-*A*
I	Same	2.78	.136	1.23	.11	2.70	.71	3,945	.15	228	.145	+38.0%	2,244	.25	47,300	3-*C*
J	Same	2.16	.167	1.04	.10	2.93	.80	4,144	.14	241	.160	+47.2%	2,377	.23	52,150	4-*A*
K	Same	2.46	.179	.64	.10	2.89	.90	3,860	.15	241	.150	+37.6%	2,529	.29	48,100	4-*B*, 4-*C* and 8-*B*
L	75% Steel, 1¼% Si.-Mn, 4¼% Fe.-Si, 19½% High-test Ret.	2.84	.148	1.57	.09	2.95	.78	3,910	.14	255	.160	+41.2%	2,422	.25	56,700	5-*A* and 9-*A*
M	Same	2.44	.158	1.12	.11	3.14	.89	3,864	.14	241	.160	+22.3%	2,372	.26	45,350	.....
N	Same	2.32	.190	.84	.13	3.08	.79	3,747	.15	228	.150	+21.4%	2,370	.24	43,800	.....
O	Same	2.32	.150	1.23	.11	3.09	.83	3,651	.14	241	.170	+22.3%	2,709	.31	46,100	.....
P	Same	2.87	.167	1.04	.10	2.78	.71	3,710	.14	228	.140	+22.9%	2,459	.25	41,650	.....
Q	Same	2.47	.158	1.17	.12	3.05	.85	3,960	.15	241	.160	+37.5%	2,457	.25	53,500	.....
R	Same	2.38	.142	.88	.12	2.97	.83	3,923	.15	241	.175	+27.1%	2,460	.27	47,650	.....
S	Same	2.13	.183	.71	.14	2.63	.90	3,843	.13	255	.165	+35.1%	2,547	.23	46,300	5-*B*

NOTE.—This table is a record of the characteristics of heats of high-test cast irons.

Combined carbon generally is higher than with regular iron mixtures.

45. The Brinell hardness is considerably higher than with regular iron mixtures and, unlike regular iron mixtures, shows very little variation from outside to center of the arbitration bar. Regular mixtures average 207 on the outside of arbitration bars, but the center varies from 207 to 149. Table 11 shows the uniformity in hardness from outside to center of the arbitration bar on several heats of high-test iron.

46. In general, but not always, the graphite is finer and more uniformly sized and distributed than in regular iron mix-

Table 11

VARIATION IN BRINELL HARDNESS OF ARBITRATION BAR

Outside	Center
228	217
241	228
241	241
241	228
255	241
228	228
269	255
241	241
255	241
241	228

tures. Photomicrographs in Figs. 3-*C*, 4-*A* and 5-*B* show fine graphite in network form.

47. Graphite varies considerably from the outside to a point half way between the outside and center of the machined tensile piece. Fig. 4-*B* is taken at the usual place, but Fig. 4-*C* is taken on the outside of the machined tensile piece. It will be noted that the fine network graphite is very much more pronounced toward the outside.

48. Fine graphite is not always responsible for high strength. Note, in Fig. 5-*A*, ordinary graphite; Fig. 9-*A*, however, shows mostly fine pearlite going into sorbitic stage (tensile, 56,700 lbs.). Fig. 3-*B* shows fairly ordinary graphite, but the structure shown in Fig. 8-*A* is mostly all pearlitic.

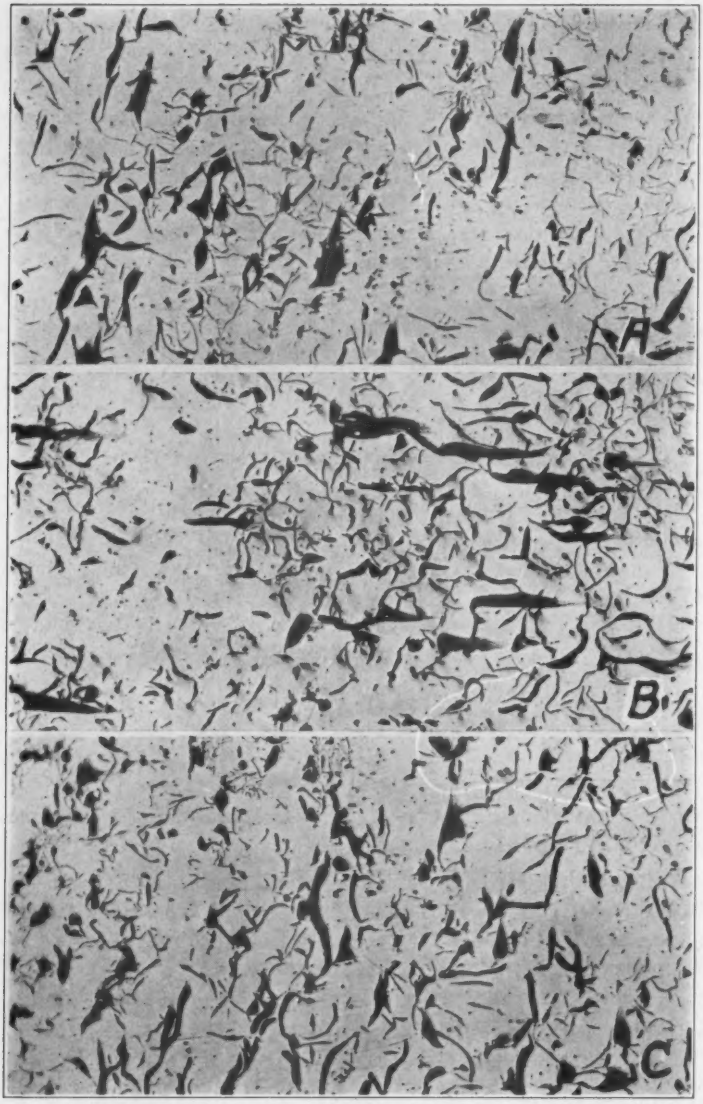

FIG. 2—IRONS FROM REGULAR IRON MIXTURES OF TABLE 9. UNETCHED. X 100.
A: MIXTURE NO. 1.
B: MIXTURE NO. 2.
C: BASE MIXTURE NO. 3, SHOWING EFFECT OF MOLYBDENUM ADDITION; COMPARE WITH TABLE 13, FIG. REFERENCE 19-*A*, WHICH IS BASE MIXTURE PLUS 2 PER CENT FERROMOLYBDENUM.

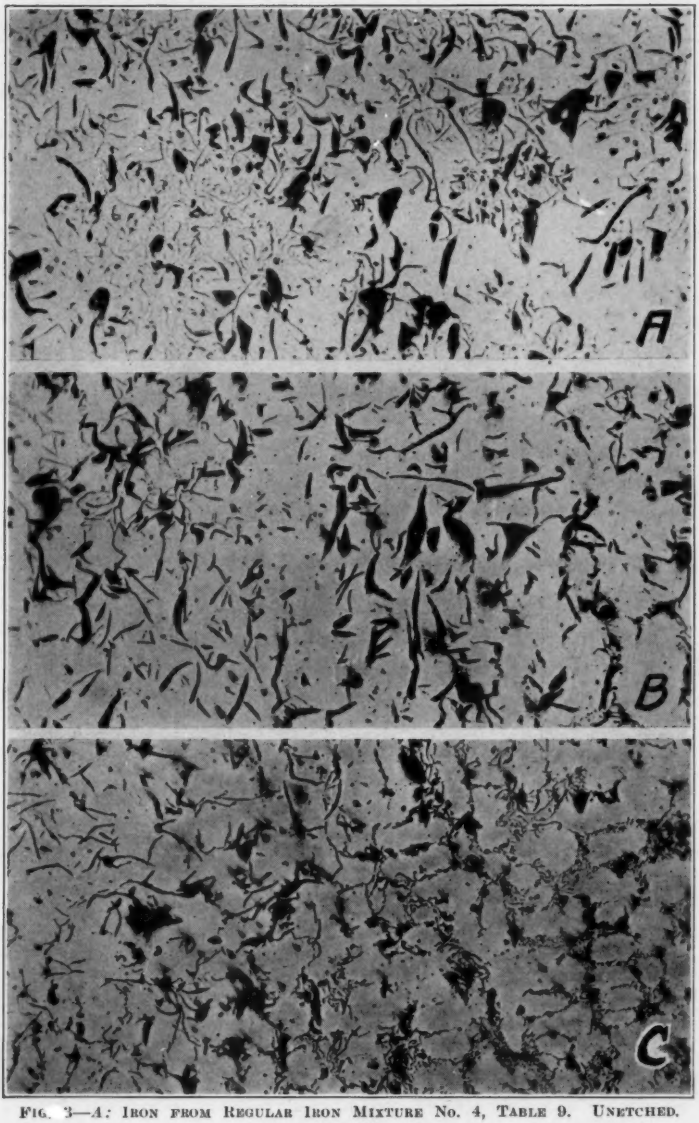

Fig. 3—*A:* Iron from Regular Iron Mixture No. 4, Table 9. Unetched. X 100.

B: Iron from High-Test Iron Heat No. H, Table 10. Unetched. X 100. Ordinary Graphite. See Fig. 8-*A*.

C: Iron from High-Test Iron Heat No. I, Table 10. Unetched. X 100. Showing Very Fine Graphite in Network Form.

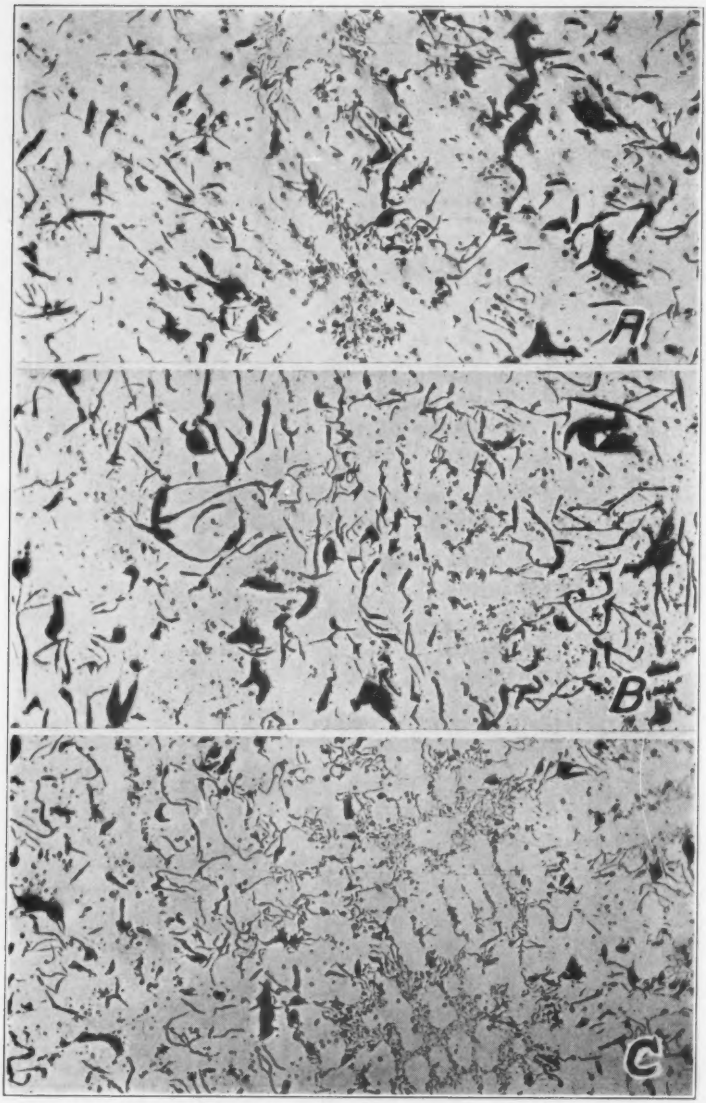

FIG. 4—IRONS FROM HIGH-TEST IRON HEATS OF TABLE 10. UNETCHED. X 100.
A: HEAT NO. J. SHOWING VERY FINE GRAPHITE IN NETWORK FORM.
B, C: HEAT NO. K. SHOWING VARIATION IN GRAPHITE FROM OUTSIDE TO INSIDE OF TENSILE PIECE.

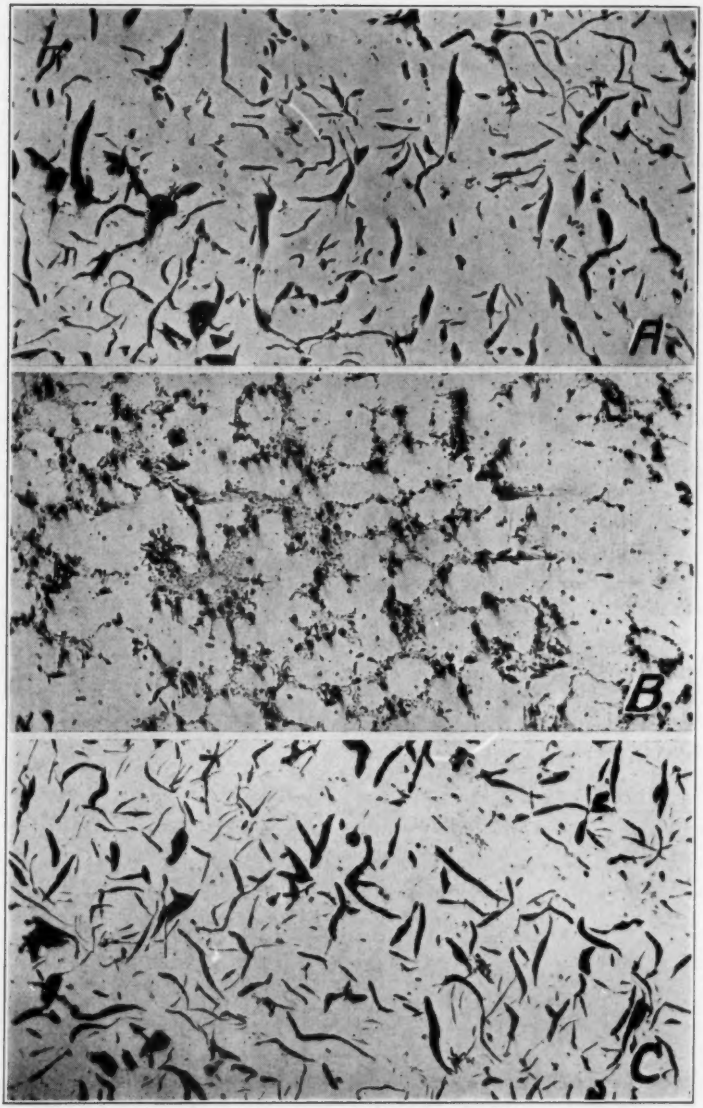

Fig. 5—*A* and *B* Are Irons from High-Test Iron Heats of Table 10. Unetched. X 100.

A: Heat No. L. Ordinary Graphite.

B: Heat No. S. Showing Very Fine Graphite in Network Form.

C: Molybdenum-Treated High-Test Iron from High-Test Plus Alloy Mixture, Table 13. Ordinary Graphite.

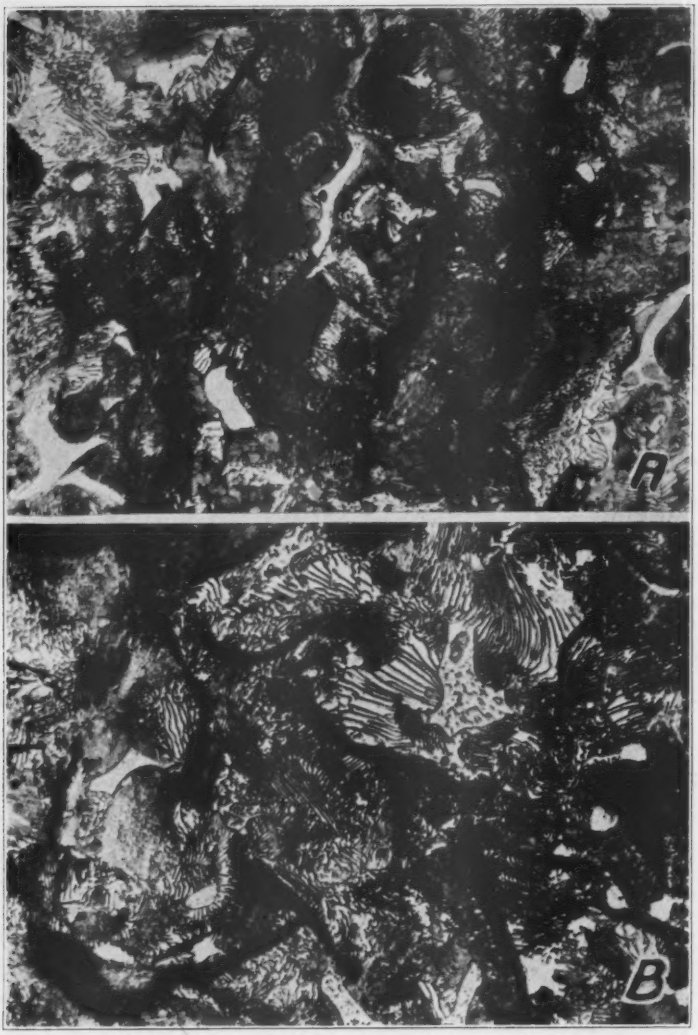

FIG. 6—IRONS FROM REGULAR IRON MIXTURES OF TABLE 9. ETCHED IN 2 PER CENT NITAL. X 500.

A: MIXTURE No. 1.
B: MIXTURE No. 2.

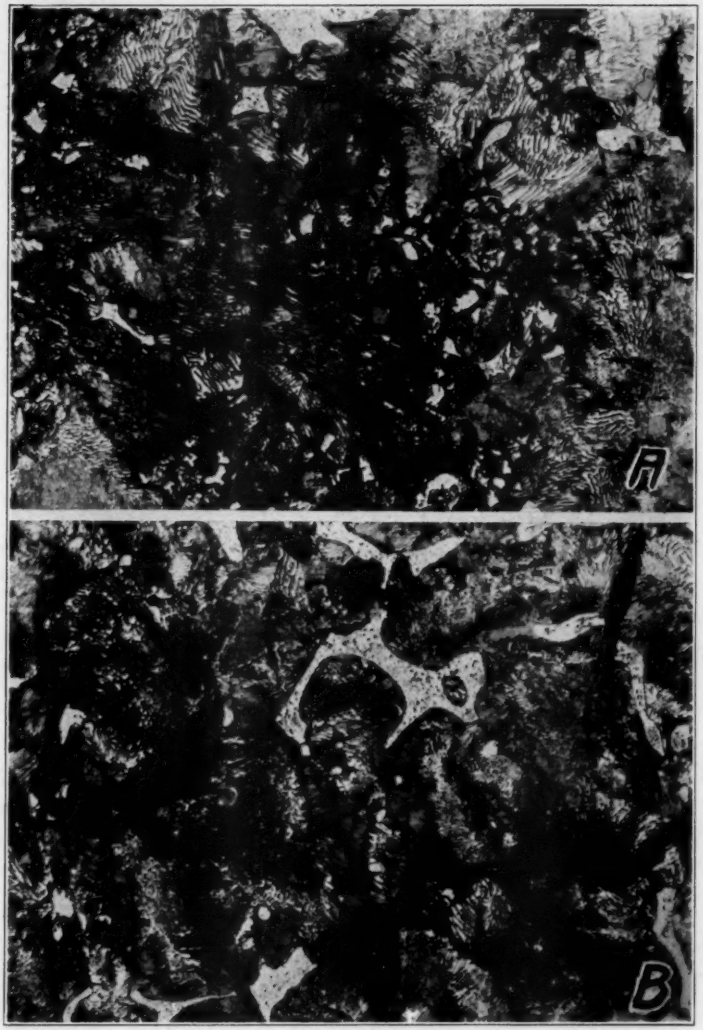

Fig. 7—Irons from Regular Iron Mixtures of Table 9. Etched in 2 Per Cent Nital. X 500.

A: Base Mixture No. 3, Showing Effect of Molybdenum Addition. Compare with Table 13, Fig. Reference 19-*B*, which Is Base Mixture Plus 2 Per Cent Ferromolybdenum.

B: Mixture No. 4.

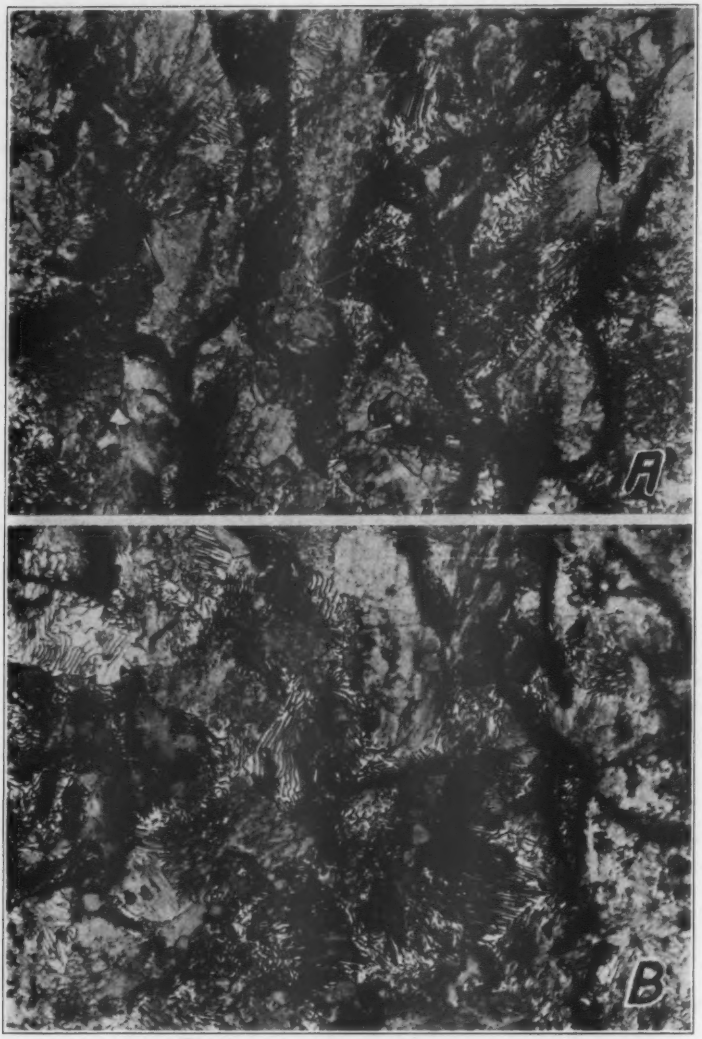

FIG. 8—IRONS FROM HIGH-TEST IRON HEATS OF TABLE 10. ETCHED IN 2 PER CENT NITAL. X 500.

A: HEAT NO. H. MOSTLY PEARLITE.

B: HEAT NO. K. SHOWING VARIATION IN GRAPHITE FROM OUTSIDE TO INSIDE OF TENSILE PIECE.

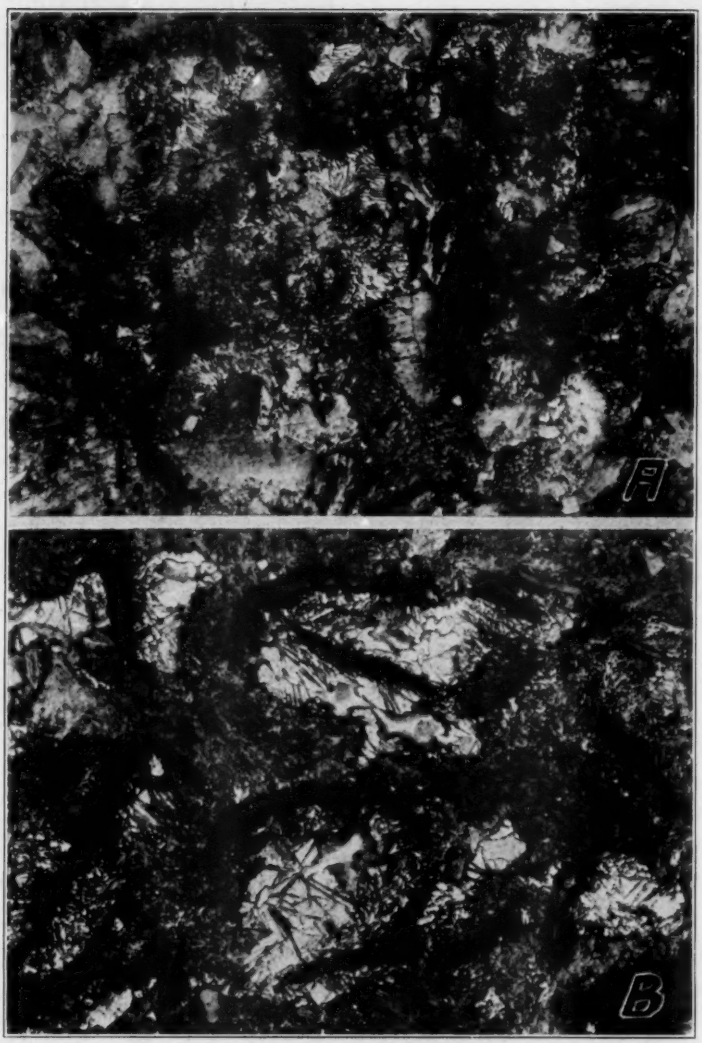

Fig. 9—*A:* Iron from High-Test Iron Heat No. L, Table 10. Etched in 2 Per Cent Nital. X 500. Showing Mostly Fine Pearlite Going into Sorbitic Stage.

B: Molybdenum-Treated High-Test Iron from High-Test Plus Alloy Mixture, Table 13. Etched as *A*. X 500. Showing Sorbitic Structure with Peculiar Needles Showing Up in White Background of Ferrite or Cementite.

49. Pattern-makers' shrinkage on solid contraction is about half way between steel and regular gray iron. It has been necessary to add more for finish on some patterns to take care of this.

50. Deflection is lower than with the usual grades of iron, unless alloys are added.

51. Transverse and tensile results are considerably higher than the results obtained with regular iron mixtures. Higher strengths and lower total carbons are obtained when two tons or more are melted.

52. High-test iron is more resistant to tool penetration than are regular iron mixtures, as indicated by drill test. This probably is due to a greater density. There is nothing in the structure, however, that would ruin a tool if reasonable feeds and speeds are carried. There is no excess cementite present if iron is of right composition, melted properly and poured into castings having no machined section less than ¼ in.

FIG. 10—MOLYBDENUM-TREATED HIGH-TEST IRON FROM HIGH-TEST PLUS ALLOY MIXTURE, TABLE 13. ETCHED IN 2 PER CENT NITAL. SHOWING BACKGROUND AND NEEDLES OF FIG. 9-*B* AT X 3000.

Fig. 11—Nickel-Treated High-Test Iron from High-Test Plus Alloy Mixture, Table 12. Unetched. X 100. Fine Graphite.

Fig. 12—Nickel-Treated High-Test Iron from High-Test Plus Alloy Mixture, Table 12. Etched in 2 Per Cent Nital. X 500. Mostly Sorbitic Pearlite.

CASTINGS POURED IN HIGH-TEST IRON

53. Fig. 13 illustrates a few of the castings made in high-test iron, with gates and risers attached. It will be noted that on the pieces of thicker section the risers are large and more like those used in steel practice. These accomplish a two-fold purpose: (1) They take care of excessive external liquid shrinkage, which would result in a depression on the upper surface without the use of risers, and (2) tend to keep the iron fluid long enough to relieve entrained slag, gas or dirt. These castings are made in dry sand (oil and facing glutrin backing).

54. Fig. 14 illustrates the same castings chipped and cleaned. The 15-in. rule in the center will indicate the approximate size.

FIG. 13—HIGH-TEST IRON CASTINGS, WITH GATES AND RISERS ATTACHED, MADE IN DRY SAND. (SEE PARAGRAPH 53.)

55. Fig. 14, *A*, shows a bevel gear blank which gave trouble with sponginess at the base of teeth and in center hole when cast in a mixture containing up to 30 per cent steel, even with low silicon content. It was formerly necessary to use chills on a surface where teeth were to be cut, and also in the center hole. This casting came sound without the use of chills when cast in high-test iron.

56. The hydraulic casting of *B*, Fig. 14, must be absolutely free from any trace of porosity or leak. At one time 16 chills were used in this casting to get it sound. This is now made in high-test iron with no chills used.

57. The hydraulic casting of *C*, Fig. 14, also must be free

from any porosity or leak. Formerly four chills were used to get this casting sound. Now it is made in high-test iron with no chills.

58. A cylinder casting is shown at *D*, Fig. 14, which must be sound in bore and of exceptionally strong, close-grained iron. This casting is satisfactorily made in high-test cast iron.

59. A screw-machine turret is shown at *E*, Fig. 14. This, when finished, has many holes bored deep into the casting. Formerly it was necessary to chill all around the iron and to partly

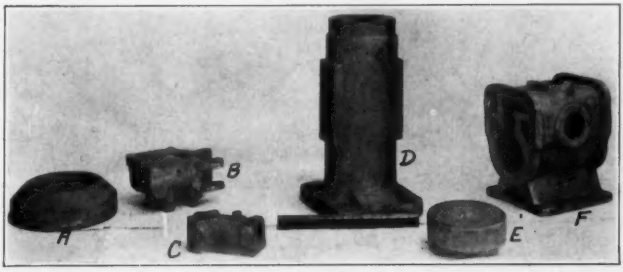

Fig. 14—High-Test Iron Castings Shown in Fig. 13, But Chipped and Cleaned. (See Paragraphs 54-60, Inclusive.)

A: Bevel Gear Blank.
B: Hydraulic Casting.
C: Hydraulic Casting.
D: Cylinder Casting.
E: Screw Machine Turret.
F: Pump Casting.

core out the center, and to chill also. Now it is made in high-test iron with no chills.

60. The pump casting of *F*, Fig. 14, must show no leakage. It was formerly necessary to chill at various corners, and even with this treatment the castings leaked frequently. These now are made in high-test iron without chills.

61. Table 12 shows analyses and physical characteristics of two heats representative of alloy high-test iron used where we have a casting of very heavy sections machined very deeply, also having a thin section that may tend to come hard unless alloy is used. Part of the silicon has been replaced by nickel. Fig. 15 illustrates castings made in this iron. The 12-inch rule indicates approximate size.

Table 12

STANDARD ALLOY HIGH-TEST IRON

		1 in. Square Bar, 12 in. Supports											Half way to Center of 1 in. Square Bar
Mixture No.	Mixture	Si	S	Mn	P	T C	C C	Ni	Transverse, lbs.	Shrinkage, inches	Brinell	Deflection, inches	Drill	Fig. No.
High Test plus Alloy	70% Steel 18½% Hi. Mn. Pig 10% Hi. Si. Pig ½% Fe. Mn 1% Pig Ni	1.73	.163	.78	.09	2.79	.66	1.39	3,755	.140	228	.14	+34.7%	11 12
High Test plus Alloy	70% Steel 18½% Hi. Mn. Pig 10% Hi. Si. Pig ½% Fe. Mn 1% Pig Ni	2.09	.160	.91	.09	2.86	.71	1.05	3,695	.160	217	.16	+24.8%	....

62. The casting at the left (*A*, Fig. 15) is a steam cylinder requiring absolute tightness and very close grain. Thirty per cent steel iron mixture would not produce a satisfactory casting. Essential closeness and absence of leaks was obtained with nickel high-test iron.

63. The casting in the foreground (*B*, Fig. 15) is a milling machine table which has been experimented with in nickel high-test iron. These are tee-slotted full length to a depth of 1½ in. and must be absolutely sound in the bottom of slots. Castings are badly porous in slots even with 30 per cent steel mixtures unless chills are used on the face. When made with the mixtures shown

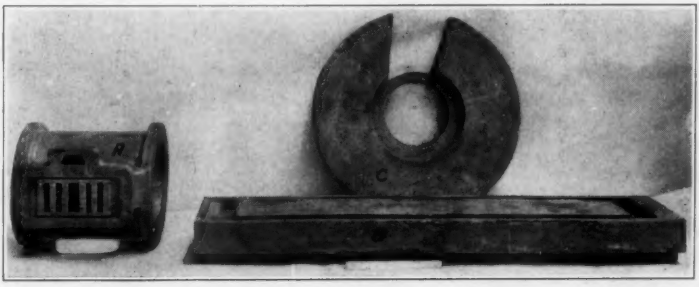

Fig. 15—High-Test Iron Castings, from Mixture in Table 12. (See Paragraphs 61-64, Inclusive.)
A: Steam Cylinder. Nickel Additions.
B: Milling Machine Table.
C: Lapping Plate, Made with Three Large Risers.

in Table 12, these are sound in slots. However, these castings took considerably longer to machine than when made with mixture No. 1 (Table 8) and chills on face, so that further experiments are being conducted, with varying percentages of nickel, silicon and steel to determine the best method of making this and similar castings.

64. The casting in the background (*C*, Fig. 15) illustrates a lapping plate made in sizes varying in thickness from 3 to 6 in. The face shown is, in use, periodically faced off until beyond the center of the piece. Each cut must show iron free from sponginess. Many mixtures were tried on this casting, using up to 30 per cent steel and as low silicon content as 0.50 per cent with no steel. The casting was cast flat and on end with risers, without

Table 13

MOLYBDENUM-TREATED IRON

Mixture No.	Mixture	1 in. Square Bar, 12 in. Supports: Si	S	Mn	P	T C	C C	Mo	Transverse, lbs.	Deflection, inches	Brinell	Shrinkage, inches	Drill	A. S. T. M. Bar, 18 in. Supports: Transverse, lbs.	Deflection, inches	Tensile strength, lbs. per sq. in.	Half way to Center of Tensile Piece Fig. No.
3	20% Steel 50% Pig 30% Returns No Alloy	1.88	.098	.76	.24	3.38	.68	0.0	3,464	.16	196	.135	—5.6%	1,994	.25	30,300	.....
3 plus Alloy	20% Steel 50% Pig 30% Returns plus ½% Fe.-Mo	1.80	.10	.80	.22	3.46	.80	0.19	3,561	.17	187	.130	+7.2%	2,125	.29	32,150	.....
3 plus Alloy	20% Steel 50% Pig 30% Returns plus 1% Fe.-Mo	1.82	.10	.73	.26	3.49	.67	0.38	3,670	.17	187	.090	+6.0%	2,559	.31	38,950	.....
3 plus Alloy	20% Steel 50% Pig 30% Returns plus 1½% Fe.-Mo	1.85	.096	.81	.23	3.45	.77	.73	3,830	.18	207	.105	+13.6%	2,692	.32	44,300	.....
3 plus Alloy	20% Steel 50% Pig 30% Returns plus 2% Fe.-Mo	1.89	.096	.80	.25	3.41	.81	.82	3,915	.17	228	.105	+19.3%	2,843	.30	47,200	19-*A* 19-*B*
High Test plus Alloy	75% Steel 19½% H.-T. Ret. 4½% Fe.-Si 1½% Si.-Mn 2% Fe.-Mo	2.92	.162	1.07	.10	2.97	.82	.82	4,138	.19	302	.140	+70.0%	3,071	.32	59,200	5-*C* 9-*B* 10

risers, with top gates, knife gates, horn gates and strainer gates. Making the casting flat, with three large risers and the mixture shown in Table 12, finally produced sound castings.

65. The photomicrographs of Figs. 11 and 12 are taken from the center of a 1-in. square bar. Fig. 11 shows fine graphite and Fig. 12 shows mostly sorbitic pearlite and is representative of structures with this iron.

Molybdenum-Treated Iron

66. Table 13 gives a record of physical properties of mixture No. 3, to which was added varying percentages of ferro-molybdenum (up to 2 per cent) at the spout, and also a heat of high-test low-carbon iron to which 2 per cent ferro-molybdenum was added. A study of this table would seem to indicate that when using up to 2 per cent ferro-molybdenum, the following results are obtained.

(a) Molybdenum raises the combined carbon but not to above the eutectoid.

(b) Molybdenum increases transverse strength considerably.

(c) Molybdenum increases Brinell hardness values.

(d) Molybdenum increases tensile strength considerably.

(e) Molybdenum increases time of machining as evidenced by drill test, but this is due to increased density or toughness and not to any hard spots or structure that would ruin a tool.

(f) Molybdenum decreases solid contraction or pattern-makers' shrinkage.

(g) Molybdenum sorbitizes the pearlite, leading to increased strength and toughness.

(h) With molybdenum present, graphite flakes appear to be somewhat smaller and more uniformly distributed and sized—a further explanation of increased strength and toughness.

(i) Molybdenum increases deflection.

Advantages of Molybdenum

67. It will be noted that molybdenum raised the strength of an ordinary semi-steel mixture equal to the strength of some

heats of high-test iron, and more than others. When this was noted, it was first thought that an iron treated with molybdenum might exhibit the same characteristics as a high-test low-carbon iron in reducing internal liquid shrinkage, porosity, sponginess or draws between adjoining thin and heavy sections.

68. Castings made with success without chills in high-test low-carbon iron were tried in molybdenum-treated irons (mixture No. 3 plus alloy, in Table 13), but invariably showed the same defects exhibited by plain mixture untreated. That is, we cannot take an ordinary iron mixture which is giving trouble with sponginess or shrink in casting and, by dropping in a little molybdenum, thereby produce a sound casting.

69. An advantage of molybdenum is that it offers a ready means of obtaining fairly high transverse and tensile strengths without using mixtures containing high percentages of steel. However, we believe that high-steel mixtures can be further improved in strength by molybdenum additions.

70. Apparently, molybdenum would be a valuable aid in insuring consistently high strengths, inasmuch as our plain high-test iron tends to vary between fairly wide limits—say, 40,000 to 60,000 lbs. tensile.

71. Comparing photomicrographs of Figs. 2-*C* and 7-*A* with *A* and *B*, Fig. 19, indicates a tendency to slightly refine graphite and sorbitize pearlite. Figs. 5-*C*, 9-*B* and 10 show the effect of 2 per cent ferro-molybdenum addition to high-test iron. Fig. 5-*C* shows nothing out of the ordinary in graphite formation. In Fig. 9-*B*, however, it will be noted that the structure is sorbitic, with very peculiar needles showing up in the white background of ferrite or possibly cementite. These needles somewhat resemble martensitic needles in quenched tool steel. Fig. 10 shows this white background and needles at a magnification of 3,000 diameters.

NICKEL-TREATED REGULAR IRON MIXTURES

72. Fig. 16 illustrates some of the castings made in nickel-treated regular iron mixtures. The main purpose of nickel in these castings is to aid machinability. As an indication of the size of the castings, *D* is 7 inches long.

73. The casting shown at *A*, Fig. 16, is a meter cover which, when poured with mixture No. 4 (Table 8) tended to come hard

on the tips of the inner projections and at extremities of the outer projections. Ferrosilicon to 1.25 per cent was first tried as a means of further softening the iron going into these castings, but resulted in a peculiar shrink hole or draw at the base of one or more of the inner projections, much similar to the draws often noted when iron is low in carbon or poured with insufficient head. Nickel to 0.5 per cent overcame this hardness without resulting draw.

74. A pump casting is shown at *B*, Fig. 16, requiring a dense and close-grained iron which must machine readily. Mixture No. 1 (Table 8), with a ladle addition of 2.25 per cent nickel gave the required properties.

75. A refrigerator piston is shown at *C*, Fig. 16, requiring a strong, good-wearing iron which must machine readily. Mixture

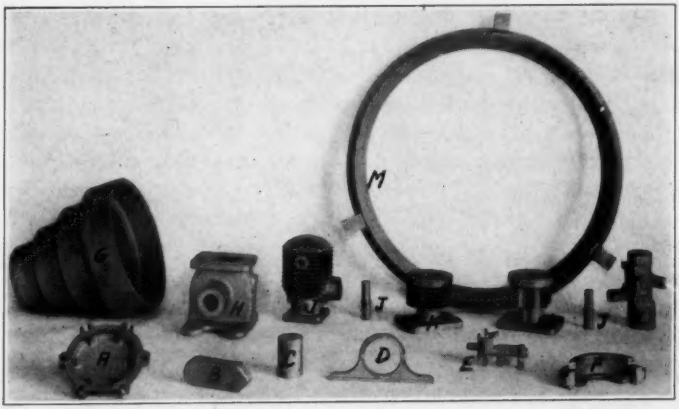

FIG. 16—ALLOY IRON CASTING, FROM MIXTURES IN TABLE 8. NICKEL WAS ADDED TO LADLE, MAINLY TO AID MACHINABILITY. (SEE PARAGRAPHS 72-85-INCLUSIVE.)

A: METER COVER. NI TO 0.5%.
B: PUMP CASTING. MIX NO. 1 PLUS 2.25 NI.
C: REFRIGERATOR PISTON. MIX NO. 1 PLUS 2.0 NI.
D: PROTRACTOR CASTING. MIX NO. 4 PLUS 1.0 NI.
E: TRAVELER CASTING. MIX NO. 3 PLUS 2.0 NI.
F: TYPEWRITER CASTING. MIX NO. 1 PLUS 1.0 NI.
G: CONE PULLEY CASTING. MIX NO. 3 PLUS 1.0 NI.
H: REFRIGERATOR COMPRESSOR BASE. MIX NO. 1 PLUS 2.0 NI.
I: LIGHTING-PLANT CYLINDER. MIX NO. 3 PLUS 1.0 NI.
J: TAPPET GUIDE. MIX NO. 3 PLUS 2.0 NI.
K, K¹: CASTINGS POURED WITHOUT CHILLS OR HARD SPOTS. MIX NO. 1 PLUS 2.0 NI.
L: CASTING WITH CORED CENTER HOLE. MIX NO. 1 PLUS 2.0 NI.
M: RING USED IN TEXTILE WORK. MIX NO. 1 PLUS 2.0 NI.

No. 1, with a ladle addition of 2 per cent nickel, gave the required properties.

76. The protractor casting shown at *D*, Fig. 16, has very thin edges (1/16 in.) which have to be milled. This casting came hard when poured with mixture No. 4 (Table 8), and ferro silicon additions to further soften resulted in rejects due to the presence of small gas holes. Mixture No. 4 with a ladle addition of 1 per cent nickel stopped the hardness without gas holes resulting.

77. A traveler casting is shown at *E*, Fig. 16, having thin edges and subject to severe wear in recess. Mixture No. 3 (Table 8) with a ladle addition of 2 per cent nickel gave the wearing quality desired with satisfactory machinability.

78. A typewriter casting is illustrated at *F*, Fig. 16, which is deeply and closely slotted for operation of key levers. These slots must be free from any trace of porosity. The design is difficult. Note the thin skirt adjacent to the body of the casting, which is slotted, and also the knife-like edges on parts of castings. When poured with an iron close enough to overcome porosity in the body of the casting, caused by draw from the skirt, the knife-like edges were chilled white. Reversing the position of the pattern in molding, locating two of the thin points in the drag, gating in at two other thin points and pouring with mixture No. 1 with a ladle addition of 1 per cent nickel, produced a sound casting without chilled edges.

79. The casting at *G*, Fig. 16, is a cone pulley which, when poured with iron close enough to overcome porosity in the corner of steps, resulted in hardness on the rim at the large diameter end. The casting is made with this end up, and iron flows up last at this point. Mixture No. 3 with a ladle addition of 1 per cent nickel resulted in a casting sound at the corner of steps and which machined satisfactorily on the rim.

80. The casting at *H*, Fig. 16, is a refrigerator compressor base. Iron sufficiently close to overcome leakage between various sections was hard or chilled white at other sections. Mixture No. 1 with a ladle addition of 2 per cent nickel overcame this trouble.

81. The casting at *I*, Fig. 16, is a lighting-plant cylinder. It came hard when poured with iron close enough to overcome a shrink hole showing up on machining and due to an adjoining thin and heavy section. Mixture No. 3 with a ladle addition of

1 per cent nickel produced a sound casting free from hardness.

82. The tappet guide (*J, J,* Fig. 16) is subject to severe wear and had to be of very close grain and hard, yet machinable. Mixture No. 3 with a ladle addition of 2 per cent nickel resulted in a satisfactory casting.

83. *K* and *K'* of Fig. 16 illustrate two castings both of which came chilled or hard when poured with an iron mixture close enough to stop a large percentage of leaking castings. Mixture No. 1 with a ladle addition of 2 per cent nickel overcame this trouble.

84. Iron close enough to overcome porosity in the cored center hole of casting *L,* Fig. 16, resulted in extremities of the thin curved section coming very hard. Mixture No. 1 with a ladle addition of 2 per cent nickel gave a sound casting free from hardness.

85. The ring illustrated at *M,* Fig. 16, is a casting used in textile work. A curved deep slot is cut into the ring, and at locations adjacent to the bosses castings frequently were found porous. Mixture No. 1 with a ladle addition of 2 per cent nickel resulted in a sound casting without machining difficulties.

Chromium-Treated Cast Iron

86. In this foundry most chromium-treated castings are of white fracture, non-machinable and in use are subjected to high heat or to very severe wear. This iron is produced by adding 1 to 5 per cent powdered ferrochromium at the spout to mixture No. 1, Table 8. A typical analysis of product is: Silicon 1.80, sulphur 0.13, manganese 0.80, phosphorus 0.22, total carbon 3.25, combined carbon 2.80.

87. Enough ferrochromium is added to produce a white fracture throughout. Such irons tend to pipe badly if the design is at all difficult. External shrinkage often develops in corners or at the junction of varying sections when chromium is high. This is overcome ordinarily by a reduction of chromium, or sometimes by a change in design.

88. Fig. 17 illustrates castings poured from this type iron. As an indication of the size of the castings, *A* is 30 inches long. The casting in the foreground (*A*) is a rail spreader for an annealing furnace. Mixture No. 1 plus 5 per cent ferrochromium gave the property desired, namely, resistance to heat.

89. The castings *B, B, B,* in Fig. 17, are sand-blast nozzles subject to severe wear. Mixture No. 1 plus 3 per cent ferrochromium gave the property desired—resistance to wear.

90. The circular piece in Fig. 17 (*C*) is one used in grinding cocoa, subject to severe wear. Mixture No. 1 plus 5 per cent ferrochromium, using dry-sand mold, gave the property desired—resistance to wear.

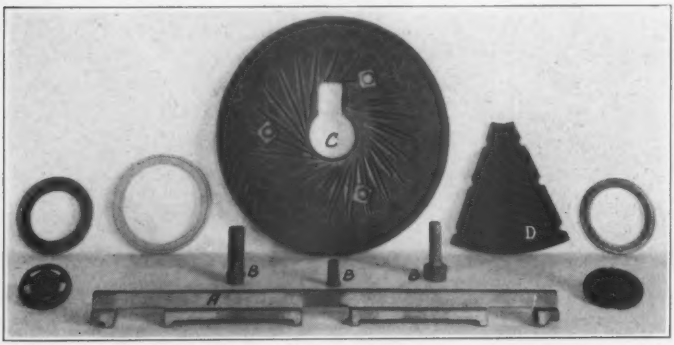

FIG. 17—ALLOY IRON CASTINGS, FROM MIXTURES IN TABLE 8. FERROCHROME ADDED, TO GIVE RESISTANCE TO HEAT OR WEAR. (SEE PARAGRAPHS 86-92, INCLUSIVE.)

A: RAIL SPREADER FOR ANNEALING FURNACE MIX NO. 1 PLUS 5.0% FERROCHROME FOR RESISTANCE TO HEAT.

B: SAND-BLAST NOZZLES. MIX NO. 1 PLUS 3.0 FERROCHROME FOR RESISTANCE TO WEAR.

C: CIRCULAR CASTING USED IN GRINDING COCOA. MIX NO. 1 PLUS 5.0 FERROCHROME FOR RESISTANCE TO WEAR.

D: SECTION OF COCOA GRINDER. MIX NO. 1 PLUS 3.0 FERROCHROME FOR RESISTANCE TO WEAR.

REMAINING CASTINGS ARE OIL-BURNER PARTS. MIX NO. 1 PLUS 1.0 TO 5.0 FERROCHROME FOR RESISTANCE TO HEAT.

91. The segment *D,* in Fig. 17, is a section of a cocoa grinder. Mixture No. 1 plus 3 per cent ferrochromium, using dry-sand mold, gave the property desired—resistance to wear.

92. The remaining castings in Fig. 17 are oil-burner parts, subject to high heat. Mixture No. 1 plus 1 to 5 per cent ferrochromium gave the property desired—resistance to heat.

93. Chromium is a powerful agent in preventing growth, as is evident from Table 14. The soft untreated iron grew five to seven times as much as chromium-treated iron. Fig. 18 illustrates the difference between three bars of chromium treated iron (*A, B, C*—chromium treated, mixture No. 1, Table 8) and one bar of untreated iron (*D*—plain iron, mixture No. 4, Table 8).

Table 14

Growth Comparison between Plain and Chromium Treated Iron

	Mix No. 4	*—Mix No. 1 plus 5% Fe.-Cr.—*		
Initial bar length, in.	11.8885	11.8000	11.8000	11.8000
10 Heats @ 1650 degs. Fahr., bar length, in.	12.1870	11.8350	11.8350	11.8600
15 Heats @ 1650 degs. Fahr., bar length, in.	12.3437	11.8550	11.8550	11.8600
Increase after 10 heats, in.	0.2985	0.0350	0.0350	0.0600
Increase after 15 heats, in.	0.4552	0.0550	0.0550	0.0600

Analysis (Mix No. 4)		*Analysis (Mix No. 1 Plus)*	
Silicon	2.34%	Silicon	2.10%
Sulphur	0.09%	Sulphur	0.10%
Manganese	0.63%	Manganese	0.67%
Phosphorus	0.38%	Phosphorus	0.18%
Total carbon	3.57%	Total carbon	3.33%
Combined carbon	0.42%	Combined carbon	2.98%
		Chromium	3.28%

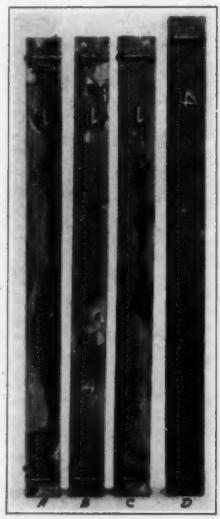

Fig. 18—Chromium-Treated Iron, Showing the Effect of Chromium in Preventing Growth. *A*, *B* and *C* Are Bars of Chromium-Treated Iron; *D*, A Bar of Untreated Iron. (See Paragraph 93.)

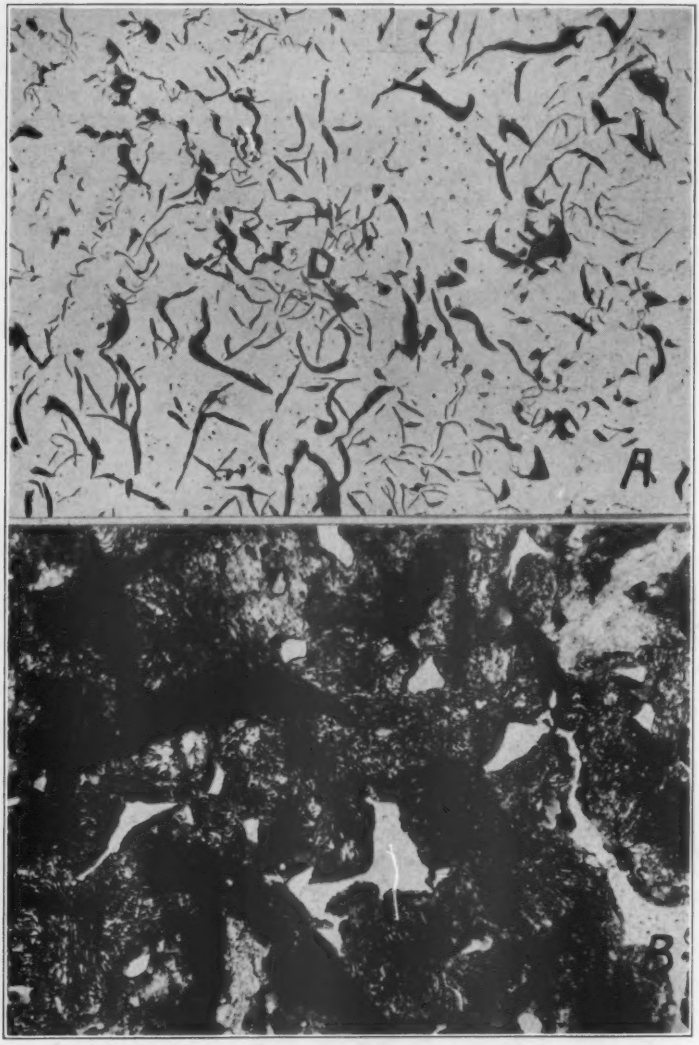

FIG. 19—MOLYBDENUM-TREATED IRON FROM REGULAR IRON MIXTURE NO. 3 PLUS 2 PER CENT ALLOY, TABLE 13.

A: UNETCHED. X 100. SHOWS TENDENCY TO REFINE GRAPHITE. COMPARE WITH FIG. 2-*C*.

B: ETCHED IN 2 PER CENT NITAL. X 500. SHOWS TENDENCY TO SORBITIZE PEARLITE. COMPARE WITH FIG. 7-*A*.

Summary and Conclusions

94. High-test and alloy cast irons should be of great assistance to the foundry trade in promoting quality in certain difficult classes of work.

95. The manufacture of castings from high-test irons requires considerably closer attention to details in melting, molding and pouring than with usual grades of gray iron and semi-steel mixtures.

96. There is a rapidly expanding market for castings having superior or special qualities, and the possibility of producing such castings should do much in advancing the gray iron industry.

97. The production of high-test castings results in higher costs, due to the necessity of using more expensive materials, more expensive molding methods, lower fuel ratios and a high proportion of foundry returns to good castings produced.

98. Castings of high-test iron do not machine quite as readily as do the usual grades of iron. They offer more resistance to tool penetration but are free from hard spots or structures that would ruin a tool, if such irons are properly made and poured into castings of proper sections.

99. Dry-sand molding generally must be followed in the production of high-test castings, to insure sound, clean and good-surfaced castings.

100. The slight variation in hardness from the outside to the center of the arbitration bar is noteworthy and a high tribute to the homogeneity of high-test iron.

101. Deflection values of high-test irons are lower than the usual grades, unless alloys are used.

102. Solid contraction (pattern-makers' shrinkage) in high-test iron is considerably higher than in the usual grades of iron.

103. In general, graphite is finer and more uniformly sized and distributed in high-test iron than in the usual grades of iron.

104. Transverse and tensile strengths are considerably higher in high-test iron than in the usual grades of iron, and tend to be at a maximum at the eutectoid point.

105. The photomicrographs for graphite study depend to a large extent on where they are taken, as there seems to be a con-

siderable variation in graphite size and distribution from the outside to the center of the tensile piece.

106. High-test iron is invaluable in overcoming internal liquid shrinkage, sponginess, draws between adjoining light and heavy sections or porosity in castings of difficult design.

107. External liquid shrinkage is much greater in high-test iron than in the usual grades of iron, necessitating the use of large risers to eliminate surface depression.

108. Nickel has a very decided advantage with certain castings in obtaining ease of machining without sacrificing closeness of grain, in elimination of chilled sections of thin castings, and in further improving the quality of high-test irons.

109. Molybdenum is of value in lessening solid contraction in increasing transverse and tensile strengths, and deflection values on both the usual grades of iron and on high-test iron.

110. Chromium is a convenient medium for readily turning a gray iron into a white iron, thereby obtaining valuable properties such as wear resistance and resistance to growth.

111. The technique involved in the manufacture of high-test and alloy cast irons will be improved as further knowledge of the subject is acquired.

ACKNOWLEDGMENT

112. The authors wish to acknowledge their indebtedness to Frank B. Coyle, International Nickel Co., for his valuable aid when beginning our experiments with high-test cast iron; to Walter M. Saunders for preparation of photomicrographic slides; to the foreman and others in the authors' plant who have by their cooperation helped in developing these irons to present status, and to Brown & Sharpe Mfg. Co., through whose generosity the presentation of this paper has been made possible.

DISCUSSION

MEMBER: What, in the authors' opinion, is the thinnest section in which iron of this type can be used without heat treatment to obtain machinable castings?

T. F. KILEY: We have made castings with a section as thin as one-eighth of an inch, which were poured with nickel alloy high-test iron, and

these castings were readily machinable. Generally, however, we do not pour castings with a section of less than one-quarter inch. We add from one to two per cent of nickel in order to maintain the machinability on a thin section.

MEMBER: Was there any relation to higher temperatures in melting the high-test iron?

T. F. KILEY: Yes, high temperatures are very important. Indeed, if the iron is at all dull, we have trouble in running the castings or else we have gas holes and slag inclusions in the castings. The temperature was 2800 degs. Fahr. according to an optical pyrometer reading.

MEMBER: Mr. Kiley, in what part of the heat do you run this high test in relation to your other iron?

T. F. KILEY: The high-test iron is run from the first part of the heat, generally one to two 1-ton charges; one ton on the bed, 300 coke split for the additional ton.

D. MCLAIN:[1] I am wondering if those present here are aware that there was a patent granted to a German in 1928 by the U. S. Patent Office for making pearlitic iron containing from 50 per cent to 90 per cent steel scrap.

F. B. COYLE:[2] There was a patent taken out by a gentleman in California a good many years ago for the use of more than 50 per cent steel as well as less than 50 per cent. That patent ran out on the first of January, 1927, so that anyone who wishes to use any per cent of steel in the cupola in this country is well protected.

H. BORNSTEIN:[3] As to the patent situation, I do not think we need worry. It seems to be the practice of the patent office to grant patents on a large number of metallurgical processes without reason for doing so, and I think this is a case in point. I know there have been similar patents granted in the malleable iron field.

In respect to the paper, I believe the experiences of the authors are very similar to those of others who have attempted to make this particular grade of high-strength iron. I think, too, that it should be pointed out that it is easier, from a foundry standpoint, to make castings which will show on test in the neighborhood of 50,000 lbs. per sq. in. than castings which will show approximately 60,000 to 65,000 lbs. per sq. in. There is less chance of foundry defects in the former.

It should be further pointed out, as the author has indicated, that this is not a cure-all in the foundry industry. It parallels somewhat the use of steel. We have low-carbon steels, we have alloy steels and we have heat-treated steels. Similarly, the big tonnage of gray iron castings will be manufactured in the low and medium field rather than in the high-strength field.

CHAIRMAN J. T. MACKENZIE:[4] Mr. Shaw, what is the English attitude on the patent situation?

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[1] McLain's Systems, Inc., Milwaukee.
[2] Research Metallurgist, International Nickel Co., New York.
[3] Metallurgist, Deere & Co., Moline, Ill.
[4] Metallurgist, American Cast Iron Pipe Co., Birmingham, Ala.

JOHN SHAW:[5] I think Mr. McLain referred to a patent on a hot-mold system of making pearlitic iron. The hot-mold system is not making any headway, and likewise has raised trouble. I think there is not much to fear from that standpoint.

There is only one thing I would like to say here, which is not quite relevant to the paper, and that is the question of temperatures. I believe it is quite time that we got down to a definite understanding of what is meant by temperature. Mr. MacKenzie has talked to me about 1600 degs. Cent. iron, but I have never seen 1600 Centigrade iron from a cupola anywhere at any time. It seems to me a correction should be made.

It would be a very good move on the part of the American Foundrymen's Association if the British and French associations were approached to come to a definite understanding as to the correction American foundrymen are going to put on their optical pyrometers. It is rather misleading to hear about some of these temperatures in comparison with what we are getting on the other side under the very best conditions.

DR. FRITZ W. MEYER:[6] On a recent trip to Europe I found that the patents on high-test gray iron are strictly recognized by the manufacturers of low-carbon high-test iron, who are paying royalties. I do not believe that the royalty is paid entirely on account of the patent—I think the royalty is more or less paid by the giving of a license to someone to guarantee service. They send their men to the different plants and the foundries are able to produce the products without difficulty.

The patent situation in Europe is, however, very much different from the American situation. A patent in Europe, after it has once been granted, is extremely hard to fight, while in my own opinion an American patent does not absolutely mean that it will hold water. In a great many cases it is a fact that having a patent granted in America is just an invitation for a lawsuit.

H. B. SWAN:[7] At the meeting of the American Electro-Chemical Society last October, the patent situation at that time was brought up by the late Dr. Moldenke. I believe the evidence in some cases as to the priority of these patents was put into the minutes of that meeting.

MEMBER: The author brings up the point of using chrome for white iron effect. I would like to ask if that is the only thing he used it for.

T. F. KILEY: We used the chrome for certain castings, such as grinders, which are subject to excessive wear, and also on burner castings, which are subject to high heat. You probably know that gray iron grows very rapidly under the action of heat and finally breaks open, the casting going to pieces. Our experience has been that chromium, in sufficient quantities to give a white fracture, overcomes this trouble.

MEMBER: Mr. Kiley, how do you make your five per cent chromium addition? I have tried to introduce some and found that I could not get the percentage of chromium anywhere approaching three per cent unless I melted the chromium first.

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[5] Southsea, England.
[6] Consulting Engineer, Rockford, Ill.,
[7] Superintendent of Foundries, Cadillac Motor Car Co., Detroit.

T. F. KILEY: I might explain that it is not five per cent chromium but five per cent ferrochromium, which gives about 3.25 per cent chromium in the casting. The ferrochromium is added in powdered form right at the spout into the iron, going into the ladle containing about 300 lbs. The chromium is in powdered form—it is just like dust.

The iron must be very hot, and it is. One reason for carrying an excessively high bed is that the iron must be very hot—it comes out at a temperature, as stated, of about 2800 degs. Fahr. at the spout.

MEMBER: I tried to introduce some chromium at one time, but I found that the grains were much larger than one-sixteenth inch in diameter and would come through and show hard spots in the castings. Have you had any experience along that line?

T. F. KILEY: Of course, the iron we produce in that way is hard; there is no question about that. It is a white fracture iron—it cannot be machined or even touched with a tool. Powdered ferrochromium is available, however.

CHAIRMAN J. T. MACKENZIE: High-chrome white iron is very sensitive to heat shock. It is very good as a heat-resisting material, if one can heat it evenly and uniformly, but it is very poor when subject to sudden shocks.

G. OLSON:[8] Why do the authors use 60 inches of coke bed?

T. F. KILEY: We use a height of coke bed at the beginning of the heat which, by experiment, we have found gives us the hottest iron we can get at the start. This is very important with us, as the tonnage of high-test iron is small, some of the sections are fairly thin, and then we have this chromium-treated iron coming along which often is poured into castings of very thin sections.

G. OLSON: I must take exception when the author says that he must have a bed of 60 inches for hot iron. It is not so; I will cut that in half and still get hot iron. If one knows how to run a cupola, one may run it in a good many different ways and get good results.

I am advocating a lower coke bed and will say that 30 inches above tuyeres is enough. I know this can be done, because I do it every day and get good hot iron.

As to the arrangement of the tuyeres, these are set 16 inches from the sand bottom. The height of the bed is, as mentioned before, 30 inches. It produces the finest iron one may want to use for anything at all.

I like to count the soaking time from the time the cupola is filled. This may be wrong, but it is my way of figuring soaking time.

Running a 48-inch cupola, this should be charged in about 30 minutes. It can be charged in shorter time, but I allow 30 minutes, and for a 72-inch cupola I allow a little more, say, up to 45 minutes for charging. In the 72 inch cupola one charges about 12 to 15 tons, and leaves it soak for 35 minutes at the most. Put the wind on and good hot iron is obtained from the first drop that comes out. There is no cold iron at the beginning, but it is all a matter of how the coke bed is prepared.

[8] Illinois Malleable Iron Co., Chicago.

One cannot dump in a whole lot of coke in the first place and put fire to it and expect to have a good, uniformly burned bed. It must be put in in small portions, and I would say that one-sixth of the amount of the coke goes in with the wood. After the wood is burning well, put in one-third of the bed charge, and when this is burned through the second one-third should go in. When this has burned through, level off with the remaining one-sixth and start charging.

T. F. KILEY: There is only one thought I had in connection with pearlitic iron. In the iron discussed in this paper, the structure is not entirely pearlitic. There is a small amount of ferrite in the structure.

As has been pointed out, the height of the bed is governed to a large extent by the height of the tuyeres, the amount of blast and furthermore by the class of work poured and the composition of the charge. As stated, the initial bed height when running high-test iron in our case was found to give hottest iron at the start when 60 inches above the tuyeres.

A Comparison of Natural Bonded and Synthetic Molding Sands for the Steel Foundry

By H. J. Cole,* Schenectady, N. Y.

Abstract

This paper deals with the comparison of the working properties of synthetic and natural bonded steel molding sands as used in actual plant practice. Data on the physical properties of the sands and clays used are given. Sample cores of the mixture used were made up and tested for strength, permeability, capillary attraction and loss of strength on heating. Gas pressure as a cause of defective castings is discussed. In a summary the author compares the physical and working properties of the two kinds of sands.

1. In our plant we have had occasion to check up the working properties of synthetic and natural bonded molding sands for steel castings, and in this paper the data secured from this work will be presented. Our purpose is not to advocate the use of one type of sand, but rather to present the facts just as they were experienced by the author, both in the laboratory and in the shop.

2. The data which we present herein deal with dry-sand facings, containing all new sand and used only on our large and best castings. The strong sand used in the natural bonded sand, and the sharp sand used in both the natural and synthetic mixtures, are both from South Jersey. Fineness test data for these sands are given in Table 1.

3. In the natural bonded sand, the strong and sharp sands

*Testing Laboratory, General Electric Co.

Table 1

FINENESS TEST DATA FOR STRONG SAND AND SHARP SAND FROM SOUTH JERSEY

Strong Sand		*Sharp Sand*	
Retained on Mesh No.	Per Cent retained.	Retained on Mesh No.	Per Cent retained.
6	none	6	none
12	0.2	12	none
20	0.4	20	1.3
30	0.6	30	6.3
40	1.9	40	25.3
50	7.3	50	36.4
70	17.7	70	21.5
100	27.1	100	6.7
140	14.5	140	1.8
200	4.4	200	0.1
270	3.1	270	0.1
Silt	6.2	Silt	0.1
Clay substance	16.6	Clay Substance	0.2
A. F. A. fineness	92	A. F. A. fineness	42
Grain class	4	Grain class	6
Clay class	F	Clay class	A

were varied in order to arrive at the best mixture. The variations used are listed in Table 2.

4. The 5 parts strong sand and 2 parts sharp sand mixture, as shown in Table 2, is the mixture that will be dealt with in this paper, because this comes within our established limits for strength and permeability.

5. The synthetic sand was made by adding 12 per cent fireclay to the sharp sand. The analysis of the fireclay used is given in Table 3.

Table 2

VARIATIONS TRIED IN MIXTURES OF STRONG AND SHARP SANDS IN ORDER TO ARRIVE AT BEST MIXTURE

Parts strong sand	7	6	5	4	3	2	1
Parts sharp sand	0	1	2	3	4	5	6
Moisture, per cent	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Green compression, lbs. per sq. in.	9.0	8.7	8.1	6.0	4.2	3.0	1.0
Dry compression, lbs. per sq. in.	120	111	80	52	41	20	8
Green permeability	40	43	54	86	110	140	163

Refractoriness of Clays

6. Clay was washed from a sample of strong sand, and tested for refractoriness in comparison with the fireclay, with the following results:

	Std. cone No.	Fusion point Degs. Cent.	Degs. Fahr.
Clay (washed from strong sand)	10	1330	2426
Fireclay (used in synthetic sand) ...	30	1730	3146

The clay that was washed from the strong sand had the following analysis: 40 per cent silica, 15 per cent iron oxide, and 20 per cent alumina.

Table 3

Analysis of Fireclay

Ignition loss, per cent	12.44
Silicon, per cent	57.32
Alumina, per cent	27.26
Iron oxide, per cent	1.82
Titania, per cent	1.44
Calcium oxide, per cent	0.19
Magnesia, per cent	0.30
Alkalies, per cent	0.20
Fusion point	Seger Cone 30-31
Mesh	30

7. Although the clay in the strong sand has a much lower fusion point than the fireclay, it has been our experience that we are troubled less with sand fusion when using the natural bonded sand. The excess sand fusion with the synthetic sand is caused by metal penetration due to the high permeability of the sand.

8. Many foundries using a synthetic sand bring down the permeability by the addition of silica flour. This method is not entirely satisfactory, as not only is the drying of the mold retarded but the backing sand is eventually filled with fines, making reclaiming more difficult. The closing up of the sand should be at the surface only, and this is accomplished by two or three applications of silica face wash, having a specific gravity about 1.9.

Milling Time

9. Samples of synthetic and natural bonded sands were taken from foundry mill at the end of one minute, five minutes, and so on up to 25 minutes, and tested for green compression strength. The results were as follows:

Minutes	1	5	10	15	20	25
Natural sand, lbs. per sq. in.	3.6	4.5	6.8	7.5	8.5	8.5
Synthetic sand, lbs. per sq. in.	3.0	4.0	5.1	5.1	5.2	5.4

10. It is to be noted that the synthetic sand reaches its maximum green strength at the end of 10 minutes, whereas the natural bonded sand reaches its maximum green strength at the end of 20 minutes. The increase in green strength of the synthetic sand at the end of 20 minutes is due to the decrease in moisture rather than to longer milling.

Table 4

COMPRESSION STRENGTH TESTS ON NATURAL BONDED AND SYNTHETIC MOLDING SANDS

Foot lbs. on core	Green Compression, lbs. per sq. in.		Dry compression, lbs. per sq. in.		Permeability	
	Natural	Synthetic	Natural	Synthetic	Natural	Synthetic
1	4.1	3.0	46	43	93	187
2	5.8	4.3	58	47	73	175
3	7.6	5.0	83	52	52	153
4	9.0	5.1	120	53	40	150

Ramming

11. Cores 2 x 2 inches square made from natural and synthetic sands were rammed various blows with a 14-lb. weight and tested for green compression strength and permeability. Compression strength data from this test are shown in Table 4.

12. It is to be noted that the strength of the natural bonded sand increases and the permeability decreases, more rapidly than with the synthetic sand, with the amount of ramming done.

Capillary Attraction

13. One series of cores was made from natural bonded sand, and one series was made from synthetic sand.

14. After baking cores for 2 hours at 180 degs. Cent. and cooling in a dessicator, each core was placed in a small pan containing 25 cc. of water which had been made slightly alkaline by the addition of a few drops of ammonia. A strip of litmus paper was placed on each core, and the time—from the moment when the core was placed in the pan to that when the litmus paper turned blue—was recorded in seconds. The data thus obtained are shown in Table 5.

Table 5

TESTS ON CORES OF NATURAL BONDED AND SYNTHETIC SANDS

(Time in seconds required for litmus paper, placed on each core, to turn blue after core was placed in alkaline solution.)

Natural bonded sand core	Synthetic sand core
21	33
21	31
20	32
20	30
21	29
23	30
20	30
21	31
22	33
—	—
Avg. 21	Avg. 31

Loss of Bonding Strength by Heating Sands

15. After 8000 grams each of natural bonded and synthetic molding sand were dried to zero moisture in an oven at 100 degs. Cent., 2000 grams of each sand were heated in a small 5-k.w. electric muffle furnace at individual temperatures of 200, 400, 600 and 800 degs. Cent. for a period of 2 hours.

16. Together with each 2000-gram sample, a 100-gram sample of each sand was placed in a furnace to obtain the loss on burning.

17. Each 2000-gram sample was cooled in a dessicator, then tempered and milled in a laboratory-size Simpson mill for 5 minutes and tested for green and dry compression strength and permeability. Table 6 lists the results obtained from this test.

18. It is to be noted that at 800 degs. Cent. the natural bonded sand has a higher green strength and lower dry strength than the synthetic sand. The higher green strength is due to the fineness of the grain, as there is no colloidal matter remaining after heating the sands to 800 degs. Cent. for 2 hours.

Defective Castings Caused by Gas Pressure

19. Of the many defects found in castings, perhaps the most troublesome is the blow-hole, especially when the cavity does not

Table 6

TESTS OF GREEN AND DRY COMPRESSION STRENGTH AND PERMEABILITY OF NATURAL BONDED AND SYNTHETIC SANDS

Natural Bonded Sand

Temperature, Degs. Cent.	100	200	400	600	800
Loss on burning, per cent	0	.12	.28	.80	1.25
Moisture, per cent	7.5	7.5	7.5	7.5	7.5
Green compression, lbs. per sq. in.	7.2	7.0	6.5	3.5	3.0
Dry compression, lbs. per sq. in.	80	74	50	6.5	0.2
Green permeability	52	52	73	77	82

Synthetic Sand

Temperature, degs. Cent.	100	200	400	600	800
Loss on burning, per cent	0	.10	.12	.50	.85
Moisture, per cent	5.0	5.0	5.0	5.0	5.0
Green compression, lbs. per sq. in.	5.0	5.0	2.2	1.0	.5
Dry compression, lbs. per sq. in.	54	55	27	4.5	1.0
Green permeability	153	153	200	298	300

show itself until perhaps 80 per cent of the total cost has been expended.

20. When molten steel is poured in a mold, large volumes of gases are formed, in the following ways:

(a) By the moisture in backing sand in a large mold working to the surface by capillary attraction and coming into contact with the molten metal, causing steam.

(b) By expansion, due to the intense heat of the air in the pores of the sand or the mold itself.

(c) By the hot metal coming into contact with the organic matter in the sand.

(d) If conditions are right, explosive mixtures will be formed by molten steel liberating hydrogen from water and combining with the air that is in the mold.

21. If these gases cannot escape through the sand forming the mold, then the mold surface, through rise in pressure, is either pushed away, causing a scab, or the gases are forced back into the metal, causing blow holes.

22. There is more gas formed in a natural bonded sand, due to its ability to take up moisture and to the great amount of organic matter present. Therefore, the backing sand used with a natural bonded sand should be more open than the backing sand used with a synthetic sand.

SUMMARY

Natural Bonded Sand	*Synthetic Sand*
Materials	
The clay content of the incoming shipments of strong sand will vary from 12 to 18 per cent.	Sharp sand more uniform.
Clay in sand not refractory.	Fireclay can be chosen from one of many firms for its refractory and bonding properties.
Cost per ton exclusive of labor, $4.25.	Cost per ton exclusive of labor, $5.85.
Milling	
Longer milling time needed to bring sand up to its maximum green strength.	Sharp sand free from clay contains little or no moisture; therefore, a definite amount of fireclay when added is better distributed throughout the sand.
More rigid control needed, as sand in shed will vary from 2 to 6 per cent moisture, and from 40 to 60 permeability.	A definite amount of water can be added, and the sand milled for a given time.
	Better control, as sand is easily standardized.

Working

Moisture range from 5 to 9 per cent; therefore, a wide permeability range.

Sand tools better on wet side. Apt to ram too hard in spots, causing blow holes and scabs.

Permeability of backing sand must be kept above 150.

Sand does not dry out readily on standing. A thinner application of silica wash can be applied.

A moisture range from 4 to 6 per cent.

Tools better on dry side.

Impossible to ram sand too hard.

More uniform ramming.

Sand drys out more readily on standing.

Permeability of backing sand must be kept above 100.

Silica mold wash should be thicker. Often two or three applications needed to prevent excess metal penetration.

If moisture is on dry side, dry strength will be low.

Sand more friable.

Drying

Contains more moisture.

Is less permeable.

Holds on to its moisture more tenaciously; therefore, takes longer time to dry.

Less cracking of mold surface.

Contains less moisture.

Sand more open; therefore, it takes shorter time for molds to dry.

Over 12 per cent clay causes cracks on mold surface.

Closing

If large mold that is not dried in center is left standing several days, moisture will work more quickly toward surface. Molds will take up dampness from foundry more quickly.

Capillary attraction is less; therefore, sand will not readily take up moisture from backing sand.

Lower dry strength, molds more easily damaged on standing.

Higher dry strength, molds not easily damaged on standing.	

Pouring

Molds should be filled quickly to prevent "cooking" of less refractory clay by radiant heat. More gases generated, as the nature of sand is ferruginous, and also due to higher moisture remaining in mold after drying.	Molds can be poured more slowly because of more refractory clay. Less gas generated, because of lower moisture remaining in sand after drying and the absence of hydrated ferric oxide.

Cleaning

Sand peels better from castings. Better surface is obtained.	Sand does not peel well from casting.
Unsound castings are usually from blow holes, pin holes and scabs.	Surface gray in color, rough and often pitted.
Cleaning cost is lower.	Unsound castings are usually from fusion due to metal penetration.
Surface is of a bluish color.	Cleaning cost is higher.

Reclaiming

Less sand can be reclaimed, due to large quantity of silt and burned clay present.	More sand can be reclaimed; many foundries are reclaiming as high as 80 per cent.

DISCUSSION

CHAIRMAN R. A. BULL:[1] Mr. Cole has presented an interesting comparison of results in one foundry on dry-sand work, and in case he did not emphasize the first two paragraphs sufficiently for everyone to under-

[1] Director, Electric Steel Founders' Research Group, Chicago.

stand what this comparison represents, I might call your attention to two sentences in the first paragraph, reading as follows:

> "Our purpose is not to advocate the use of one type of sand, but rather to present the facts just as they were experienced by the author, both in the laboratory and in the shop. The data which we present herein deal with dry-sand facings containing all new sand and used only on our large and best castings. The strong sand used in the natural bonded sand and the sharp sand used in both the natural and synthetic mixtures, are both from South Jersey."

In other words, this is not sweeping generalization that covers all sorts of practice, even in dry-sand shops, but just the data they collected from this particular and more or less restricted experience. Obviously, it would be very helpful if people who feel disposed to discuss the paper would relate their experience, whether it checks or whether it is contradictory to the data Mr. Cole has incorporated in his paper.

N. J. DUNBECK:[2] Mr. Cole, don't you think, in comparing the finishes you obtained on your castings, that a good part of the difference in finish was due to a difference in the grain size used? Am I correct in believing that you used a coarser and more open sand?

H. J. COLE: Yes, in the synthetic sands we used a coarser and much more open sand. We chose that type of sand because we thought it was about the best type to use in our synthetic sand.

We have found that sands of finer grain sizes will dry out on the floor much more readily. Also, if one wishes to reclaim the sand, the type I have mentioned is much more suitable. The finer the grain, of course, the less reclaiming properties it will have.

PAUL BECHTNER:[3] Which sand does the author think is best?

H. J. COLE: I can only say, from our experience, that our cleaning costs have gone down considerably by using the natural bonded sand, although since using the natural bonded sand we have improved our mold wash considerably and have better drying facilities. I would not say that the decrease in our cleaning costs is due wholly to the natural bonded sand; there are other things that enter into it. However, I believe it is a big factor, and the only way we can judge is by our cleaning costs, which at the present time run much below 90 cents a hundred pounds.

MEMBER: Has the author had any trouble, in using synthetic sand, from the sand drying out too quickly before using? Was the drying out retarded?

H. J. COLE: We had considerable difficulty with the synthetic sand drying out, and many suggestions were offered. Some thought we should put a little glycerine in our mill, but we finally overcame the difficulty by putting burlap bags over the sands the minute they were milled and brought to the foundry floor.

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[2] Chief Service Engineer, Eastern Clay Products, Inc., Buffalo.
[3] Vice-President, American Colloid Co., Chicago.

CHAIRMAN R. A. BULL: Did you ever use crude oil?

H. J. COLE: No, we never used crude oil.

I might add here that the fineness of the clay used in synthetic sand has much to do with the sand drying out before it is used. Some time ago we tried out a car of air-floated clay which gave us much trouble. The finer the clay, of course, the more quickly will it air dry after being milled into the sand.

P. E. MCKINNEY:[4] I believe that this question of sand is somewhat of a local issue; it depends largely on the freight rates of desirable sands that are available for making up synthetic mixtures. For a good many years I was strongly in favor of natural bonded sand, but there is one difficulty with which every foundry is confronted, and that is the non-uniformity of natural bonded sand.

Successive cars of sand will come in, some of them containing clay pockets; in other words, the piles that are unloaded will have portions that run quite high in clay. Unless it is very carefully handled and very carefully tested, batches are apt to go through the mixer which will give tight rammed castings, which cause difficulties.

I believe a good deal of the trouble that was referred to with synthetic sands lies in the proper selection of a clay to go with the particular sharp sand base which can be mulled in such a way as to surround each of the individual grains with the proper amount of bond and the proper physical contact of the bond with the sand. Personally, I believe that with careful sand control such as is maintained in many of the foundries, and with good sand reclaiming facilities, synthetic sands offer economies without depreciating the qualities of the finished product that cannot consistently be obtained with natural bonded sand.

CHAIRMAN R. A. BULL: Mr. Cole, to what principal factor or series of factors do you attribute the better peeling that you obtained with your natural bonded sand?

H. J. COLE: The clay in the natural bonded sand is the principal factor. I would say that the iron oxide is in a hydrated state, more so than it would be in fireclay, and I believe that hydrated iron oxide goes a long way in giving a good peeling effect on the casting. Also, a natural bonded sand can be rammed very hard to prevent metal penetration. These factors make for good surface conditions on the casting.

CHAIRMAN R. A. BULL: They counteract, then, the less refractory conditions that you find in your natural bonded sands? I notice your loss on burning for your natural sand is higher than for your synthetic sand.

H. J. COLE: Yes, the good peeling qualities of the natural bonded sand counteract the low fusion point of this type of sand. There is more organic matter present in the natural bonded sand, which accounts for the higher loss on burning.

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[4] Metallurgical Engineer, Bethlehem Steel Co., Bethlehem, Pa.

PAUL BECHTNER: I notice that your sharp sand has an A. F. A. fineness of 42. Is not that an extremely coarse sand?

H. J. COLE: It will be noticed that the extremely coarse material and the extremely fine material are absent. This should make an ideal sharp sand.

PAUL BECHTNER: Almost a washed sand?

H. J. COLE: Yes, about 0.3 per cent silt and clay substance.

PAUL BECHTNER: Your natural sand has a fineness of 92, which seems rather fine for a steel sand. Have you ever tried anything between the two in synthetic sand?

H. J. COLE: It will be noticed in my paper that the natural bonded sand is composed of 5 parts strong sand and 2 parts sharp sand. Thus, 92 is the fineness number of the strong sand, and not of the natural bonded sand.

PAUL BECHTNER: It seems to me that the trend is toward a little finer sand than 42 grade.

H. J. COLE: In green-sand work, where no silica wash is applied, I would say that the finer sands are the logical sands to use.

PAUL BECHTNER: As you say in your paper, a good many of your defects were due to penetration?

H. J. COLE: That penetration is metal penetration. With a synthetic sand, that can be overcome by one or two applications of a fairly thick silica wash.

PAUL BECHTNER: Why not use finer sand in the first place?

H. J. COLE: If a finer sand is used, other troubles will occur. Finer sand dries very readily after being milled, and one cannot dry as well in the oven with finer sand; the permeability is lower. I believe the best type of synthetic sand is a coarse sand with the surface closed with a good wash of silica powder.

PAUL BECHTNER: Our feeling is that most molding sands can be lowered in grain size to advantage, especially in synthetic sand. Of course, we are talking now about dry sand, but even in dry sand the feeling of the suppliers of synthetic sand bond is that finer grains will work better than coarser grains in synthetic sand. We can get permeability of 150 with an A. F. A. fineness of 70.

In other words, a permeability good enough to make small and medium-size steel castings can be obtained with sand that formerly was considered much too fine. There are steel companies today making good steel castings with sands that run 65 and 70 A. F. A. fineness; that is, in green sand.

Mr. Cole's paper is about dry sand. Here we have contrasting trends:

The coarse-grained synthetic sand dries out more quickly in the oven; at the same time, there is a complaint that it dries out too quickly on the floor. Those factors might be compromised a little, reducing, at the same time, the tendency to penetration.

I suggest to Mr. Cole, as a further experiment, that a finer sand be tried in synthetic dry sand.

CHAIRMAN R. A. BULL: Mr. Cole, in a spirit of fairness, does indicate in his conclusions that the use of natural bonded sand is more apt to result in blowholes. I have no doubt the author would be glad to consider any constructive suggestions anyone is inclined to make.

The point that he makes that the skin of the sand has dried, being a defective factor, is perfectly true, of course. However, I think some of the steel foundrymen are very much inclined to feel that the skin does not always stay put in the form of silica wash. Consequently, they depend not entirely on the wash but to some extent on closing up the grains inside. That, of course, is illustrated by a good many large cores in which silica flour is deliberately introduced and which, when washed, has a very refractory effect.

R. W. MCCANDLISH:[5] In reference to Mr. Bechtner's remarks, I would not consider that a very coarse sand; it shows only about 25 per cent on the No. 40 mesh sieve. I would say that the low fineness number is due to the uniformity of the sand, such a large percentage lying between 30 and 70.

PAUL BECHTNER: I was looking only at the final figure, the A. F. A. fineness number 42.

J. M. SAMPSON:[6] We have used both kinds of sand for a good many years. We were using natural bonded sand and broke away from it, and I must admit that my successor went back to the natural bonded sand.

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[5] Vice-President, Standard Silica Co., Chicago.

[6] Foundry Engineer, General Electric Co., Schenectady, N. Y.

X-Ray as Production Tool to Improve Quality of Aluminum Alloy Castings

By E. M. Gingerich* and H. J. Rowe,* Cleveland

Abstract

As X-rays offer an instrument for the investigation of castings to insure production of sound parts, the Aluminum Co. of America has installed outfits in two of their foundries to study problems connected with aluminum casting. In the installations, safety considerations were carried out. A description of the installations is given, and applications for development and control are cited. Detection of blow holes, porous spots, and also of shrinkage are shown to be of value in improving methods of gating, feeding and pouring. Experience is shown to be necessary in proper interpretation of X-ray data. The use of viewing boxes to give stereoscopic images is shown to be of advantage in locating defects in very intricate castings.

Introduction

1. The history of X-rays in several respects parallels that of aluminum. Both are relatively twentieth century developments, and since their conception have shown remarkably fast progress in numerous fields.

2. In looking back over the history of X-rays since their discovery by Rontgen in 1896, with the development (by Coolidge in 1911) of a suitable method of producing the rays, their sensational use by physicians as an instrument for diagnosing and treating human ailments, and their rather isolated use in universities and research laboratories for the experimental examina-

*Aluminum Co. of America.

tion of metal parts, one wonders why the X-ray has not been used more extensively by industry. In industry, the foundry has been one of the first to realize the advantages of the X-ray and to appreciate the benefits which would result from its use.

3. It is not the purpose of this paper to go into detail on the theory of X-rays, this subject having already been treated quite thoroughly in a number of previously published papers. It is more our purpose to show how the modern X-ray equipment can be employed by the foundry as a tool for the development and control of foundry technique. By so doing, we hope to show that the use of X-ray equipment by the foundry not only insures a better and more uniform product, but also results in certain labor-saving and scrap economies.

Principles of X-Ray

4. One of the distinguishing characteristics of X-rays is their ability to penetrate matter which is opaque to ordinary light. Like visible light, X-rays travel in straight lines from their source, decreasing in intensity as they are absorbed by the various media through which they pass. Roughly, the absorption coefficient of a material is proportional to its density, a dense and heavy material such as iron absorbing the rays more than a less dense material such as aluminum.

5. It is this property that makes it possible to study the heterogeniety of opaque matter. Strictly homogeneous material of uniform thickness will absorb X-rays equally throughout any exposed area, while the presence of less dense material such as gas inclusions, or more dense material such as heavier metallic segregations, will decrease or increase the absorption.

6. X-rays, therefore, on passing through opaque material present an invisible shadow picture composed of shadows of different density, corresponding to the accumulated absorption of the various materials through which the rays have passed.

Limitations of Fluoroscope

7. There are several methods of detecting X-rays and transferring their invisible shadow picture into visible records. Screens coated with a fluorescent salt, such as calcium tungstate, can be used under favorable conditions for examining certain classes of

material (*a*, Fig. 1). The instrument employing such a screen is known as a fluoroscope.

8. The fluoroscope, although having certain advantages in speed and economy, particularly for medical diagnostic work, is rather limited in its use for X-ray examination of metal parts. The fluorescent screen is almost instantaneous in effect and hence must be energized with sufficiently intense X-rays to enable it to produce a satisfactory shadow picture. This condition limits its use to relatively thin metal sections.

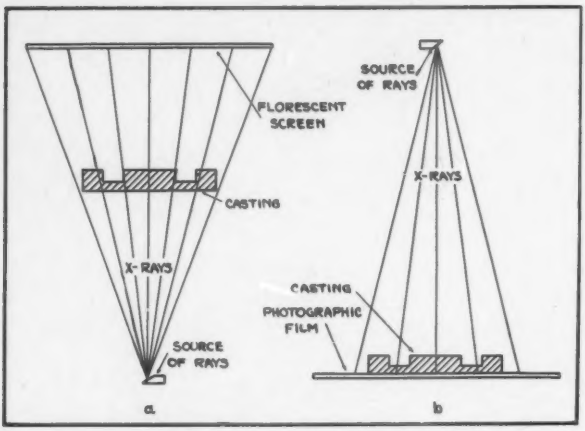

FIG. 1—*a*: SKETCH SHOWING PRINCIPLE OF FLUOROSCOPE.
b: SKETCH SHOWING PRINCIPLE OF RADIOGRAPHY.

Explanation of Radiography

9. Photographic films are sensitive to X-rays and, hence, can be used for detecting X-rays. A photographic X-ray film, after being exposed to the X-rays passing through the medium being examined (*b*, Fig. 1), can be handled in the same way as an ordinary photographic film, insofar as developing the film is concerned.

10. By the use of the photographic film as a means of recording the shadow picture, a permanent record is available which permits sufficient time for study. The photographic films register a cumulative X-ray effect which provides greater sensitivity than

can be obtained with a fluoroscope, and permit the examination of considerably heavier metal sections. The examinations described later in this paper were all carried out by means of the photographic method, generally known as radiography.

Application of Radiography to Foundry

11. The foundry is called upon continually to provide more accurate and complete inspection methods in order to meet the demand for higher quality castings. The increasing use of castings, and especially aluminum-alloy castings, by the aeronautical industries has created a need for more exhaustive inspection. This demand has required an extensive study of the best foundry technique for each individual job, and an absolute method of controlling this technique once it has been found.

12. The progressive foundry at the present time is the one which has developed its products in accordance with this demand and has gained its customers' confidence by the consistent uniformity of the castings produced.

A Tool for Developing Foundry Technique

13. Experience has shown that radiography is an efficient tool for developing and controlling foundry technique. X-ray equipment eliminates the necessity of fracturing or sectioning castings to determine their soundness, thereby avoiding the destruction of the casting.

14. Then, too, there is always the chance of missing important defects if sectioning alone is relied upon, to say nothing of the hesitancy on the part of both foundryman and customer to section castings which are thought to be sound. Often, therefore, internal defects are not revealed until the casting has failed in service. Such failures always have retarded the use of castings in highly stressed parts.

15. The use of X-ray equipment by the foundry, eliminating the destruction of castings by sectioning and insuring adequate inspection, together with controlled foundry technique, has made it possible for the engineer to use castings with a greater assurance of safety. Parts heretofore made by more expensive methods of fabrication because of the insufficient reliability of castings, now are being cast to a greater extent.

X-RAY EQUIPMENT AS USED BY FOUNDRIES OF ALUMINUM CO. OF AMERICA

16. The installation of X-ray equipment for the examination of metal parts such as castings requires some little consideration. For general miscellaneous work in which castings of various sizes and shapes are to be considered, the X-ray equipment must be flexible enough to be adapted readily to the examination of all types and sizes of castings. The X-ray tubes preferably should be mounted so as to allow sufficient adjustment for exposures in any plane. The source of high voltage necessary for operating these tubes must be variable in order to obtain maximum contrast for any section thickness.

Safety Considerations

17. The injurious effect of X-rays to the human body necessitates the protection of the X-ray operator and any others that might be within active distance of the source of rays. The X-ray room, therefore, should be lined with lead of sufficient thickness to prevent penetration by the rays. Safety devices are desirable to insure that no one can enter the X-ray room while the apparatus is in operation.

Description of Installation

18. The general type of X-ray apparatus used by the Aluminum Co. of America in its foundry installations originally was developed for medical work. The X-ray tubes themselves are set up in lead-lined rooms (Fig. 2), the doors of which are provided with safety switches which prevent anyone from entering the X-ray room without automatically shutting off the power.

19. Two types of tube mountings are available, one an adjustable table equipped with a high-voltage tube for use with castings of heavy section; the other, an adjustable-stand mounting particularly useful with large castings that cannot be easily handled. To facilitate the handling of the large castings, a monorail hoist is provided.

20. The high voltage, 50,000 to 200,000 volts, is obtained by means of a step-up transformer and mechanical rectifier. The low voltage for filament heating is obtained by a step-down transformer. Suitable leads, properly insulated, run from the rectifier and step-down transformer to the X-ray tube.

FIG. 2—INTERIOR OF LEAD-LINED X-RAY ROOM SHOWING MECHANICAL RECTIFIER AND X-RAY TUBE MOUNTED ON ADJUSTABLE STAND. LEAD-GLASS WINDOW AT EXTREME LEFT PERMITS OPERATOR, AT CONTROLS IMMEDIATELY OUTSIDE ROOM, TO VIEW THE TUBE WHEN IN OPERATION. NOTE CASTING AND FILM IN ALUMINUM CASSETTE SET UP FOR AN EXPOSURE.

FIG. 3—X-RAY ROOM VIEWED FROM OUTSIDE THROUGH THE OPEN DOOR, SHOWING CONTROL PANEL AND METERS.

21. The control panel always is placed outside of the operating room (Fig. 3). From here the operator can control the various apparatus by means of suitable equipment and meters. The interior of the X-ray room can be viewed at all times through a lead-glass window which offers adequate protection from the X-rays.

22. Certain other accessories are required in the X-ray room for preparing a casting for radiographic examination. These include film holders, lead sheet and shot and barium clay for blocking out various sections of the casting, and filter and intensifying screens for reducing secondary radiation and exposure time, respectively. Necessary photographic dark-room facilities for developing and printing the exposed films also are provided.

Limitations as to Section Thickness

23. Besides the section thickness limitations of the X-ray equipment, as determined by the density of the material to be penetrated and the size of the X-ray tube (voltage across the tube), there are certain limitations with respect to the type and size of defects which can be satisfactorily revealed. Some of these limitations can be partially overcome by the proper orientation of the casting to be examined and by the selection of a favorable film distance, tube voltage and time of exposure.

24. With suitable conditions, it has been found possible to detect cavities 1/16-inch thick in an aluminum alloy casting eight inches thick, providing the cavities are located in the half of the casting nearest the film. Cavities smaller than this in sections of this thickness, even though present, could not be detected on the radiograph. In sections of aluminum alloy castings two inches thick, cavities have been detected as small as 1/64-inch in thickness, while in sections of one inch or less, pin-hole porosity can be detected that cannot be seen on a machined surface.

APPLICATION OF X-RAY FOR DEVELOPMENT CONTROL IN FOUNDRY

25. The previous discussion has described briefly the X-ray equipment, and has attempted to show the scope of such equipment in the foundry. In the following pages, a number of more concrete examples of the use of the X-ray for development and control of aluminum-alloy foundry technique are given. It is fortunate, perhaps, that aluminum alloys, because of their relatively low

density, lend themselves to X-ray examination much more readily than do some of the more dense ferrous and nonferrous alloys.

Successful Application of X-Ray

26. In the foundries of the Aluminum Co. of America, the X-ray has proved to be a valuable aid in overcoming casting difficulties. It has been employed both in determining the foundry technique which will give the most satisfactory casting and as a production check in order to maintain the original standards.

27. In a number of cases the X-ray has been included as a part of routine inspection. The use of the X-ray for complete or partial inspection depends upon the importance and the quantity of the castings involved. The X-ray, of course, is not a foundry "cure-all," but when properly used, and the knowledge derived from it properly applied, it becomes a very handy tool.

28. The increasing use of complex alloys and patterns of intricate design are taxing the foundryman's skill to produce sound castings. Up to the present time, most alloys which develop high physical properties show a tendency toward greater internal shrinkage in castings.

29. Defects caused by these tendencies can be more easily detected by X-rays than by other means. By proper correlation of X-ray examination and casting technique, such defects can be more readily eliminated.

CORRELATION OF X-RAY AND FOUNDRY TECHNIQUE FOR IMPROVING QUALITY OF CASTINGS

30. It is well known that there are a number of foundry variables which affect the quality of castings. The location of gates, risers and chills, the physical properties of the sand together with the moisture content, and the type of cores used are of equal importance to the alloying practice, the melting practice and the pouring technique.

31. The effect of these variables and the result of improper foundry technique usually are detectable by X-ray examination. Porosity, shrinkage and cracks are the most common internal defects which may occur in aluminum-alloy castings. These usually are caused by poor foundry practice which can be corrected if the detrimental effects are known.

32. The design of present-day castings often is such that it is difficult to use with success alloys whose casting characteristics are not exceptionally good. In such instances it is quite important that the foundryman should know whether such castings are sound. X-ray examination affords a rapid and accurate means of detecting the presence of defects. The following more specific examples may serve to illustrate better the use of the X-ray.

Blowholes.

33. Blowholes in aluminum-alloy castings often are troublesome and may result in rejections after expensive machining has been performed. It is necessary, therefore, that production castings should be as absolutely free as possible from this type of defect.

34. Blowholes are attributed largely to improper pouring or gating and often can be eliminated by correcting the pouring technique. Blowholes in castings may be uncovered by sand blasting if they occur just under the outside surface. However, if the blowholes occur on the interior of castings, they must be detected by other means.

35. The X-ray is especially adapted to detect blowholes in castings. This is followed up by determining the effect of various changes in technique introduced to overcome the trouble.

36. Fig. 4, *A* and *B*, show the improvement made in the quality of castings by the elimination of blowholes. This was accomplished by the change of gating shown in Fig. 5, *A* and *B*, together with reduction of metal pouring height.

37. To illustrate the effect of pouring height alone, radiographs of two cast slabs are shown in Fig. 6. One of these slabs was poured from a distance of twelve inches above the mold and the other from a distance of two inches above the mold.

Porosity.

38. It is a well-known fact that sand castings are prone to be more or less porous because of the difficulty encountered in controlling their solidification shrinkage. This effect can be greatly reduced by careful control of foundry practice such as pouring methods and pouring temperature, gating, chilling and feeding.

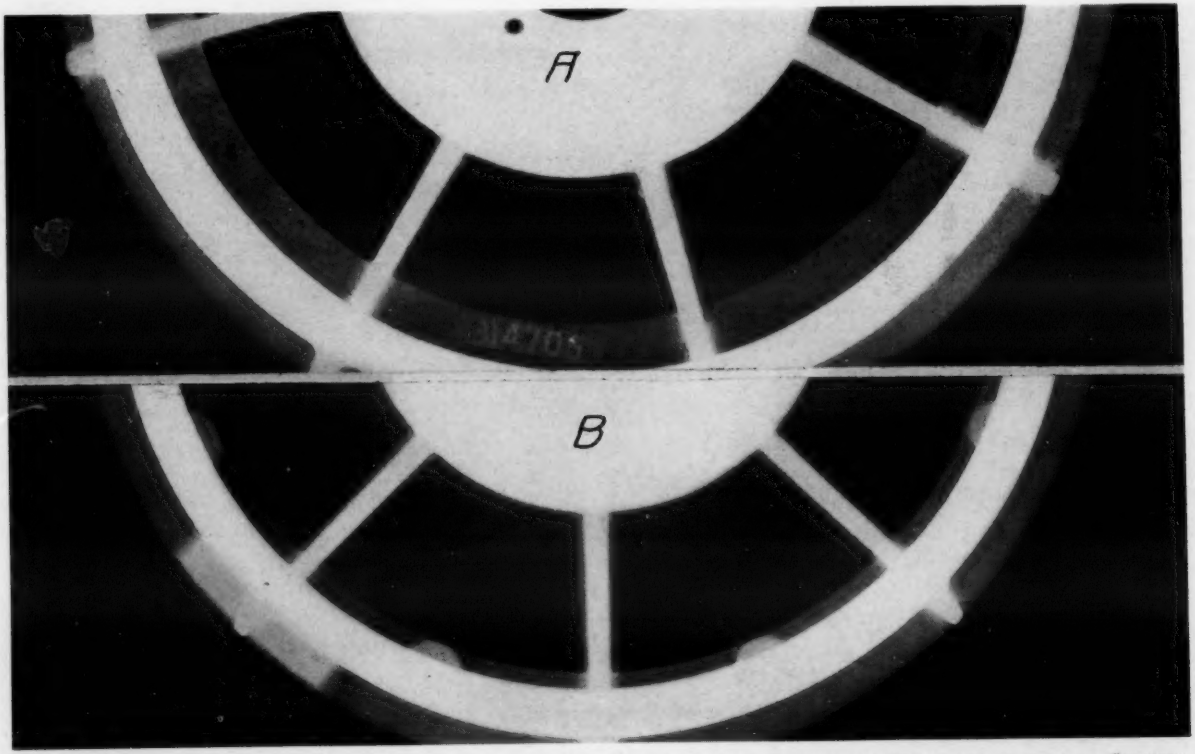

FIG. 4—*A*: RADIOGRAPH OF SECTION OF AERONAUTICAL BRAKE-DRUM CASTING, SHOWING PRESENCE OF BLOWHOLES AS WELL AS CONSIDERABLE POROSITY. *B*: RADIOGRAPH OF SECTION OF AERONAUTICAL BRAKE-DRUM CASTING AFTER CHANGES IN GATING SHOWN IN FIG. 5 HAD BEEN MADE AND POURING HEIGHT REDUCED TO MINIMUM.

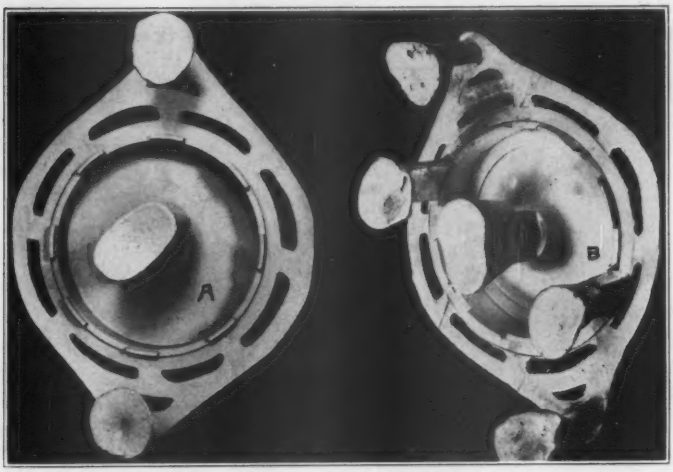

FIG. 5—*A*: GATING USED FOR CASTING SHOWN IN FIG. 4-*A*, RESULTING IN BLOWHOLES. SLAB AT BOTTOM WAS POURED FROM HEIGHT OF ABOUT 2 INCHES WHICH, TOGETHER WITH A MINIMUM POURING HEIGHT, ELIMINATED BLOWHOLES AND POROSITY.

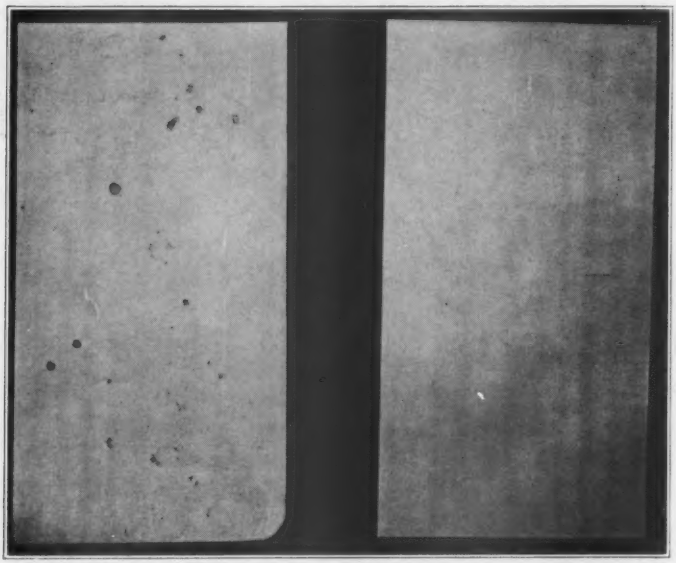

FIG. 6—RADIOGRAPHS OF TWO CAST SLABS. SLAB AT LEFT WAS POURED WITH LIP OF LADLE 12 INCHES ABOVE MOLD AND SHOWS PRESENCE OF NUMEROUS BLOWHOLES. SLAB AT RIGHT WAS POURED FROM HEIGHT OF ABOUT 2 INCHES AND SHOWS NO BLOWHOLES.

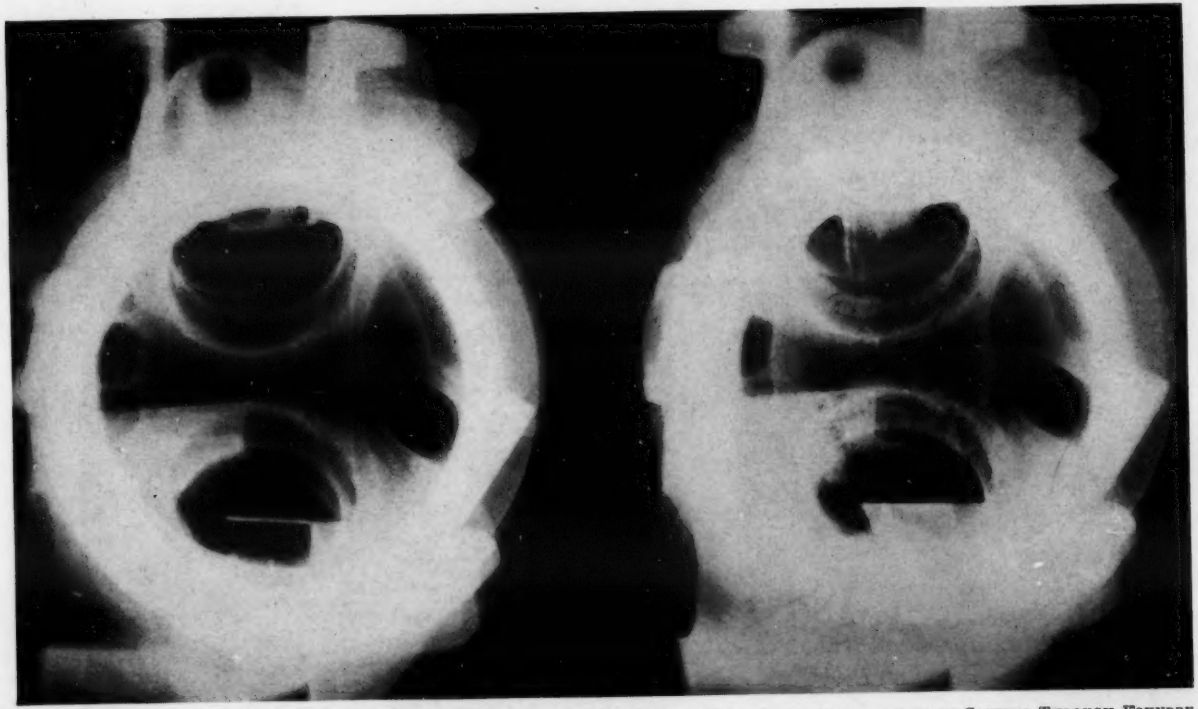

FIG. 7—RADIOGRAPHS OF TWO ALUMINUM-ALLOY AIR-COOLED CYLINDER HEADS, ILLUSTRATING IMPROVEMENT IN CASTING THROUGH FOUNDRY TECHNIQUE. CASTING AT RIGHT SHOWS SPONGINESS IN CENTER.

39. In many instances, it is necessary to make a number of changes in these factors before satisfactory technique is developed. X-ray examination of castings affords a rapid check upon the results of such successive changes and is a valuable aid in this respect.

40. The use of X-ray has aided materially in the development of aluminum-alloy cylinder heads and pistons for aircraft engines. The design of these parts has been far from simple, and the casting characteristics of the alloys most suitable for this purpose are not of the best. The result has been that porosity, shrinkage and dross inclusions were the most troublesome factors to overcome.

41. To what extent this has been accomplished is shown in Figs. 7 and 8. These radiographs illustrate the improvement effected in the soundness of an air-cooled cylinder head and piston.

Shrinkage.

42. Solidification shrinkage often takes the form of pin-hole porosity or shrinkage. This usually occurs when light sections adjoin heavy sections in castings, and when the latter are not ade-

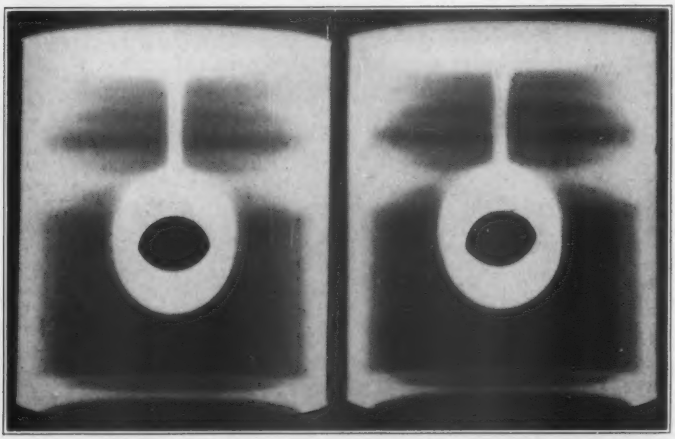

FIG. 8—RADIOGRAPHS OF TWO ALUMINUM-ALLOY PISTONS, SHOWING ELIMINATION OF INTERNAL DEFECTS POSSIBLE THROUGH SATISFACTORY POURING PRACTICE. CASTING AT LEFT BY ORIGINAL METHOD SHOWS DEFECTS.

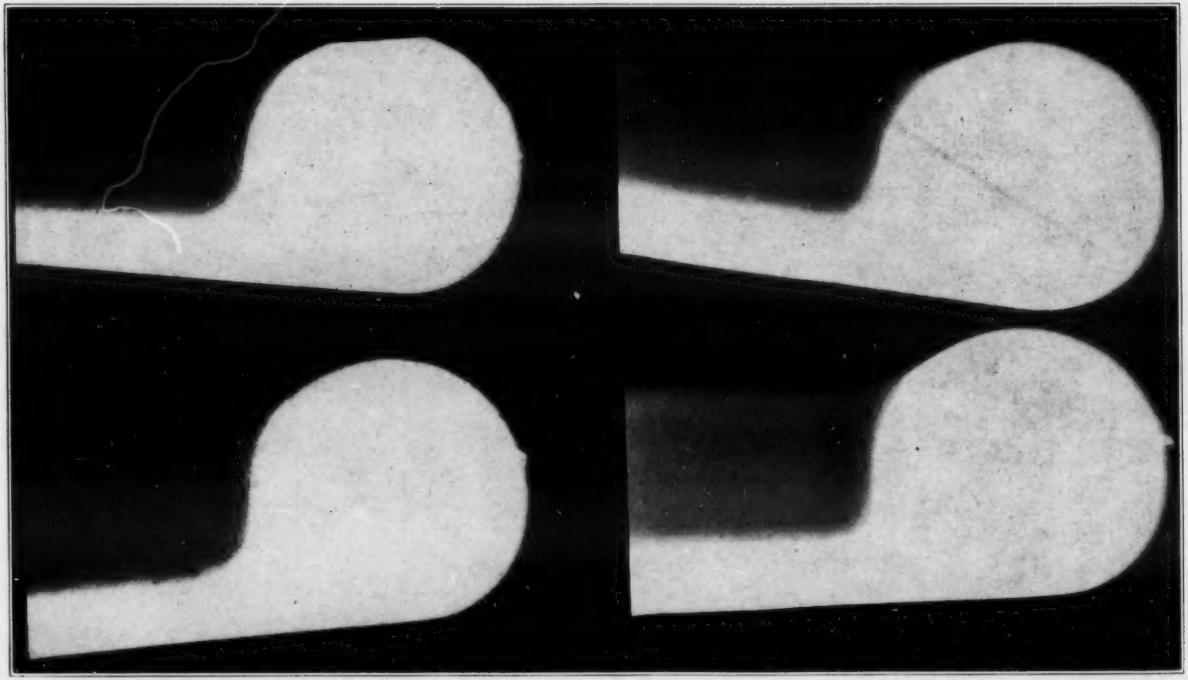

FIG. 9—RADIOGRAPHS OF SEVERAL SECTIONS OF ALUMINUM-ALLOY SAND CASTINGS. CASTINGS AT LEFT SHOW APPRECIABLE SHRINKAGE, WHILE THOSE AT RIGHT SHOW DEFECTS REMOVED THROUGH CHANGE IN GATING SHOWN IN FIG. 10.

quately fed. Shrinkage may or may not show on the surface of the casting. This type of defect often seriously affects the strength of the casting and must not be present in castings subjected to severe service stresses.

43. The X-ray can be used satisfactorily to detect the presence of pin-hole porosity or shrinkage. It is possible in most instances to eliminate the cause of this type of porosity by increased feeding, and in this the use of the X-ray is especially valuable.

44. The radiographs of Fig. 9 show the presence of shrinkage in two aluminum-alloy castings. This shrinkage was removed as shown by the change in feeding accomplished by the gatings shown in Fig. 10.

CONTROL OF PRODUCTION BY X-RAY INSPECTION

45. The development of a foundry technique apparently satisfactory for a production casting does not necessarily mean that this technique will continue to be satisfactory indefinitely. In other words, some castings fail to "stay put" and occasionally will

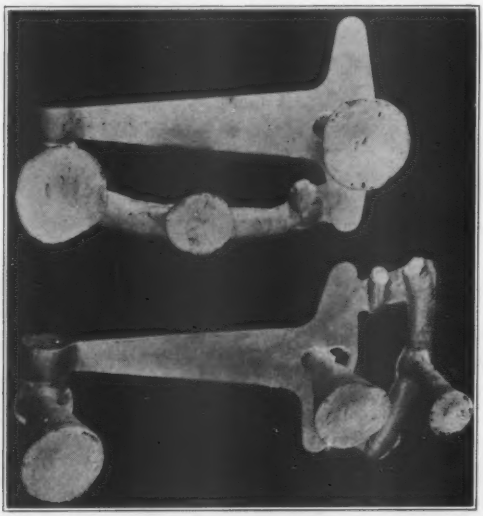

FIG. 10—TWO METHODS OF GATING CASTINGS FROM WHICH SECTIONS SHOWN IN FIG. 9 WERE TAKEN. GATING SHOWN ABOVE PRODUCED SHRINKAGE NEAR HEAVY LUG AT LEFT, WHILE LOWER GATING ELIMINATED THIS TROUBLE.

develop some defect, for reasons often difficult to determine.

46. If defects are of a surface nature, they will be detected and proper measures taken to correct them; but if the defect is internal in nature—shrinkage or porosity, for example—a varying number of defective castings might be made before the defect has been detected.

47. For this reason, it has been found good practice to make a periodic check upon the quality of production castings. While this sometimes may be done by fracturing or machining the castings, it can be done more quickly and more accurately by the use of the X-ray. In addition to this, the inspected casting is not destroyed.

48. The importance of producing sound aircraft castings makes the use of the X-ray a highly desirable tool for inspection purposes. The extent to which this method of inspection is used depends upon the quantity of castings involved.

49. If a large number of pieces are required, only a certain percentage may be radiographed. If only a few castings are produced daily, it may be necessary to make a complete X-ray inspection of all such castings.

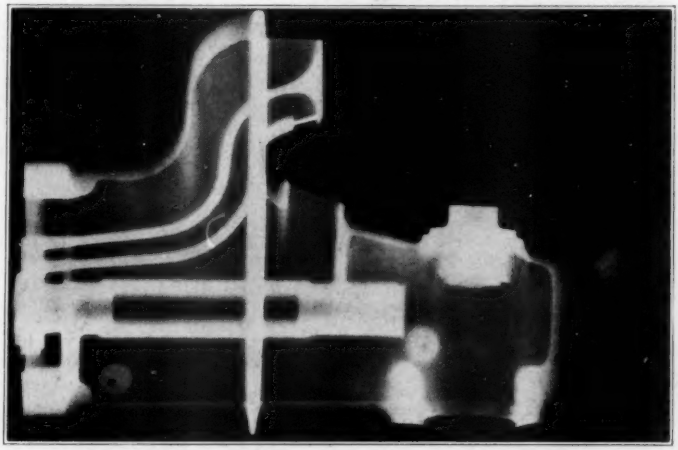

FIG. 11—RADIOGRAPH OF ALUMINUM-ALLOY OUTBOARD MOTOR CASTING TAKEN AT RANDOM FROM PRODUCTION FOR INSPECTION PURPOSES.

Use of X-Ray with Intricate Castings

50. It has been standard practice to make a more or less complete X-ray inspection of certain intricate castings at the start of a production run. As the foundry practice is improved and the defects eliminated, it becomes necessary to select at random only a limited percentage of the total castings from each lot for X-ray as a matter of routine check.

51. Fig. 11 shows a radiograph of an outboard motor casting taken at random from production for check purposes. Because of the nature of this casting, it is even possible to check core shifts from the radiograph.

52. Fig. 12 shows two castings from a lot of sand-cast connecting rods for an experimental engine. These rods were examined one hundred per cent by X-ray, as a part of the routine inspection. The reason for rejection of one of the rods is quite apparent from the radiograph.

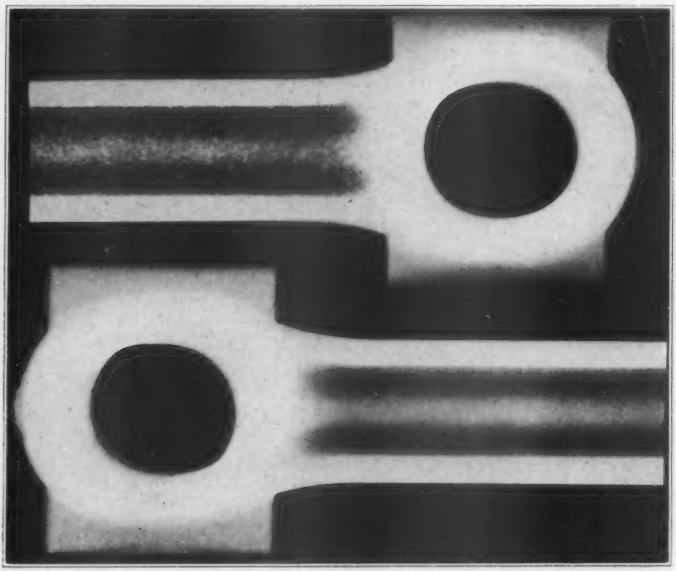

FIG. 12—RADIOGRAPHS OF TWO ALUMINUM-ALLOY CASTINGS FROM A LOT INSPECTED BY X-RAY. REASON FOR REJECTION OF CASTING ABOVE IS QUITE APPARENT.

INTERPRETATION OF X-RAY EXAMINATION

53. The interpretation of radiographs, and the identification of the various defects that may be shown by an X-ray film, is not always an easy task. It requires considerable experience on the part of the X-ray operator in comparing radiographs with the actual sectioned casting before he is able to interpret a film satisfactorily in terms of the nature of the defects shown.

54. Even at best, there are a few instances where the exact nature of the defect cannot be determined. In many cases, this condition can be corrected by a second exposure of the section in another plane.

Overcoming Limitations of Equipment

55. Mention has already been made in this paper of the section limitations of the X-ray equipment described. Mention also has been made of the minimum size of cavity that can be satisfactorily shown on a radiograph. This is based on a maximum tube voltage of 200,000 volts.

56. With smaller equipment, having a maximum tube voltage of 120,000 volts, the maximum section thickness that can satisfactorily be examined is reduced from eight inches to five inches. These are limitations that can be overcome only with higher voltage X-ray equipment. Sections in excess of this are infrequent in aluminum castings; hence, this limiting feature is seldom encountered.

57. Besides the above-mentioned section considerations, there are several other factors worthy of mention which might affect the final interpretation of a casting radiograph. Surface irregularities of a casting are reproduced on the radiograph and care must be exercised to see that these are not interpreted as internal defects. Oxide, and dross in thin films and cold shuts, present in a casting in a plane perpendicular to the X-rays during an exposure, often are missed while examining the radiograph because the defect constitutes such a small percentage of the section.

58. Different types of defects in various planes of a casting often are superimposed on the film and may lead to a misinterpretation. By taking X-ray exposures at different angles, these difficulties are eliminated.

Advantages of Viewing Box

59. In order to gain as much information as possible from a radiograph, the conditions under which it is examined should be carefully controlled. A viewing box is desirable, supplied with a variable source of diffused light and in which the negative to be examined can be placed. The box should be placed in a darkened room so that all the light that reaches the observer comes through the film. Adjustable shields make it possible to view only those sections which are of interest, and the variable light source will take care of the difference in densities of the various films.

60. By having two viewing boxes mounted in line with each other with their faces parallel and a mirror arrangement between them for viewing both boxes simultaneously, a stereoscopic examination can be made. Such an apparatus is shown in Fig. 13.

61. The impression gained in examining two radiographs taken with the X-ray tube shifted between exposures a distance corresponding to the inter-pupillary distance, one in each viewing box, is that of three dimensions, the addition of depth enabling the observer to locate a defect in two planes. This type of examination is used only on very intricate castings to locate exactly the defects that may be present.

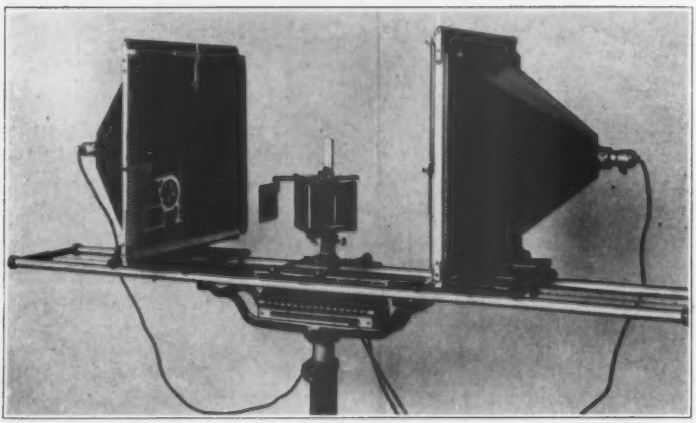

FIG. 13—STEREOSCOPIC VIEWING BOX WHICH FACILITATES STUDY OF RADIOGRAPHS.

ECONOMIC VALUE OF X-RAY EQUIPMENT

62. Radiographic examinations are of little economic value unless the observed results are used to improve foundry practice. To X-ray castings merely for inspection purposes, without applying the knowledge gained to the improvement of future castings, is expensive and does not give the maximum returns possible.

Cost of X-Ray Examination

63. The cost of X-ray examination increases with the size of the casting examined. By careful consideration of the kind of castings benefiting by X-ray examination, superfluous expense can be eliminated. Certain castings such as ornamental work, covers, etc., subject to low stresses do not warrant other than a visual examination. Aircraft parts, automotive parts, etc., subject to high stresses warrant X-ray examination during the development of the casting technique, after which occasional checks are sufficient providing the foundry practice remains the same.

64. Very large castings sometimes warrant one hundred per cent X-ray inspection of those sections which have given casting difficulty and which are highly stressed. X-ray examination of such castings, even though seemingly expensive, usually proves cheaper in the long run than other methods of inspection, some of which would destroy the casting.

65. It is quite difficult to give an estimate of the actual cost of X-ray examination in terms of cost per casting or cost per pound, because of the number of variables entering into this determination. However, based on an average monthly use of 200 to 300 square feet of film, as well as other items such as depreciation of equipment, material, labor, etc., the average cost of X-ray examination has been one to two dollars per square foot of film.

66. These figures, of course, depend to a considerable extent upon the nature of the castings and the rate at which the equipment is depreciated. The cost per casting likewise would depend upon the above factors, together with the number of castings that could be examined per square foot of film.

Comparison of Costs with Results

67. If the cost of X-ray inspection is compared with the cost of the other methods of inspection giving the same information,

keeping in mind the ultimate reduction in scrap which is evident with the use of the X-ray, we believe that the costs are comparable. In the final analysis, we feel certain that the foundry with X-ray equipment that can insure the customer the highest quality castings, will show greater economic savings over a period of time than a foundry without this equipment.

Acknowledgment

68. Acknowledgment is made to Drs. W. L. Fink and K. R. Van Horn for their constructive criticism and for the radiographs reproduced in this paper.

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DISCUSSION

E. W. PAGE:[1] I am very glad the authors have shown a few of the possibilities of the use of this X-ray equipment in the foundry. There are many more than have been described. I feel sure that such investigations, particularly in these times, are necessary to help bring the foundry out of its present position.

I listened to a paper at this convention and was very much concerned with some of the remarks made in dicsussing it. After a great deal of trouble had been taken to show some of the difficulties that exist in foundry practice, and after the remedies had been gone into by this individual, the comment was made that if one is looking for certain things, one is bound to find them.

That is not a healthy situation for anyone. It makes no difference whether the X-ray or any other tool is used; to benefit foundry processes, those tools must be used to get the most out of them. Do not sit back and listen and accept the troubles and let them go as if they were a necessity. They are not a necessity, and as soon as the foundry begins to realize that the troubles existing are something that can be controlled, the better it will be for the foundry.

There is a necessity for the foundry to sell a service and not a specification. Materials are purchased today according to certain specifications, probably from a chemical analysis. I think it is not going to be very long before that will be changed and the purchaser will buy according to service. That is when the interest will be aroused as to materials which will offer the service for which they are purchased.

E. G. FAHLMAN:[2] The Aluminum company has done a wonderful work by creating an interest in X-rays. The small foundry, however, probably will look at the results and say, "It is something I would like to have, but I can't make use of it because I can't afford to invest the money for this type of service."

We ourselves are one of the small foundries, and at the present time the investment required for equipment such as has been described is almost beyond us. However, we have found a means of making use of X-ray equipment in studying castings, and for the benefit of the small foundry people I should like to relate it.

In a large city there usually are some doctors who make a specialty of X-rays. These men usually are connected with one of the larger hospitals. Very often, however, they have their own private offices which are very elaborately equipped with X-ray equipment.

One might think that a doctor would not take an X-ray of a casting; that he is interested in his own line of business only. Such is not the case, however. Often, with his large investment in X-ray equipment, he hardly gets sufficient return from it in his normal type of business.

Consequently, if the foundryman brings such problems as he has to

[1]General Electric X-Ray Corp., Chicago.
[2]Permold Company, Cleveland.

these doctors, they will gladly, and for a very nominal consideration, X-ray his castings. We actually have made use of such a situation to our advantage.

There is just one thing to remember, however, and that is that the doctors probably do not have tubes large enough to go through very thick castings. Nevertheless, there are many small castings a study of which by the use of the X-ray may be very helpful, and the medical men can always take care of these.

CHAIRMAN SAM TOUR:[3] This matter of X-rays, of aluminum castings particularly, is something which has been before the various Association meetings for a number of years. In a number of cases, in order to prove the great value of X-rays as a means of examination, particularly bad castings have been selected—castings which normally need no X-ray examination to prove them worthless.

The thing to really keep in mind in connection with X-ray examination of aluminum castings is not to work on the very bad castings, but to improve the good ones. An X-ray picture of a casting that shows about twenty per cent of the section made up of holes, and which, if merely dropped on the floor, would break and show up all the holes, does not prove that X-rays are exceptionally good as a means of inspection.

The type of defects which have been shown in the paper presented here are ones that the X-ray is in a particularly good position to find and which cannot be found very well by any other means.

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[3]Vice-President, Lucius Pitkin, Inc., New York.

The Moore Hot-Blast Cupola

By Jas. T. MacKenzie,* Birmingham, Ala.

Abstract

Operating conditions demanding a consideration of cupola melting other than by the cold-blast process, a survey of existing installations of hot-blast cupolas led to development of a method of suspending vertical pipes inside the cupola. This installation was so satisfactory that other cupolas in this plant were changed over to hot-blast melting. Description of the installation is given, together with operating records showing variations in temperature and amounts of coke consumed in comparison with the cold-blast process.

1. The principles of the application of hot blast to the cupola have been so well stated by Vial[1] that it is not thought worth while to discuss these principles again. The purpose of the present paper is to describe the installation at the plant of the American Cast Iron Pipe Co. at Birmingham, Ala., which has been in operation since November, 1927.

Operating Conditions Require Varying Output

2. The conditions of operation are rather trying from the cupola standpoint, as it is demanded that the cupolas furnish maximum speed at some times, while at other times they are required to "stand-by," and after a shut down it is necessary that the first ladle blown up shall be hot. This requirement is primarily responsible for a rather heavy coke burden and equipment for producing high blast, as it is found that with high blast and heavy coke burden this condition can be met.

3. As the foundry increased its capacity, however, it was apparent that the cold blast cupola must either have the coke

* Metallurgist, American Cast Iron Pipe Co.

[1] Vial, F. K., "The Hot-Blast Cupola." *Iron and Steel* (Transactions, A. I. M. E.), vol. 51, no. 8, Jan.-April, 1929, pp. 21-30.

reduced to where it could not stand a long shut down, or else some better means be found for producing high temperatures.

4. After a careful survey of existing installations it was decided that these were not suitable, either on account of the excessive amount of space and equipment required, or from other standpoints.

Vertical Pipe Idea Developed

5. The idea of suspending vertical pipe through the abrasion zone of the cupola, blowing the wind in at the top and out through the bottom, one pipe to each tuyere, presented itself and original experiments were made to see how far down ordinary cast-iron pipe would stand in the cupolas under discussion. This level being at about six feet, it was decided to put in a trial installation, which was done in November, 1927. This original installation proved so successful in operation that three of the seven stacks of the company were converted to hot blast at the end of that year, and have been operating continuously on that basis ever since.

Details of Installation

6. The cupola is shown in Fig. 1, which gives a vertical cross-section of one wall of the cupola through the casting. Wind comes in at the bustle pipe (1), passes through a riser, and a flanged elbow (2) to the casting (3).

7. This casting is made of cast iron 1¾-inch thick, and the space between it and the shell is lined with 4-inch cupola blocks, the front part of the castings forming the abrasion zone of the cupola. The wind then passes through another ell (4) into a distributor (5) which runs all around the cupola and serves to keep some air flowing through the casting, even if the particular tuyere is stopped. It then comes on down through the tube and into the tuyere at (6).

8. The plan of the 72-inch cupola is shown in Fig. 2, which gives views at the planes indicated. Beginning at section *EF* and continuing up above the charging door, the lining is of iron brick, which, with the hot-blast equipment, do not get such extreme temperature conditions as they do with the old firebrick lining. One of the strong points of this installation is the fact that it

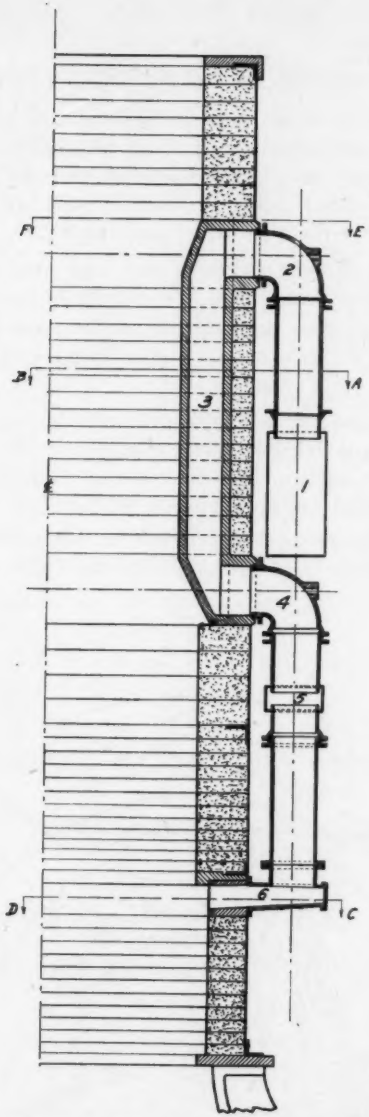

Fig. 1—Vertical Section of Cupola, Showing Arrangement for Heating Blast.

saves the wear on firebrick in the charging zone and abrasion zone.

Experiments on Best Material for Pipe

9. The casting shown here is the result of considerable experimentation. The first casting tried was rather too severe in corners, angles, etc., and it will be noted that the present model has rather easy curvatures. In fact, it is shown a little more sharply than it is actually made in the foundry.

10. A good many varieties of cast iron were used, and also some heat-resisting steel. However, the steel soon warped, due to the great difference in temperatures between the front and back, and it did not give nearly as good service as the plain cast iron.

11. At present the iron which seems to give the best results is one of approximately the same composition as ingot molds—low silicon, high carbon, low phosphorus. The average life of the present castings is approximately 75 heats of 20 hours each. When the scheme was first proposed, it was considered that if we got only 25 heats from these castings it would be well worth the trouble.

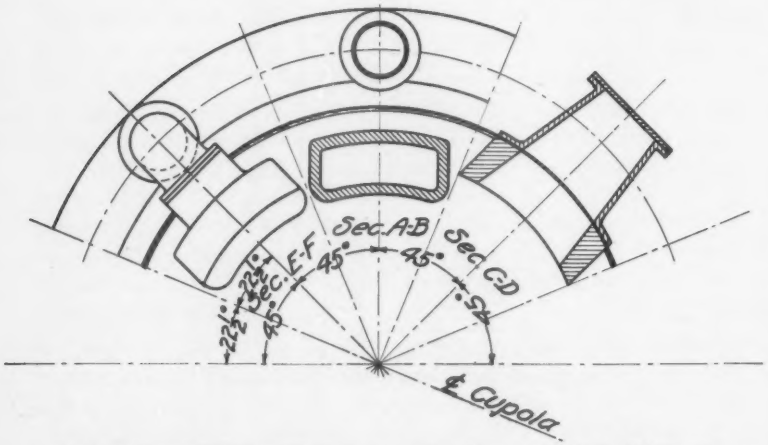

FIG. 2—CROSS-SECTION OF PORTIONS OF THE CUPOLA, SHOWING VIEWS OF PLANES OF FIG. 1.

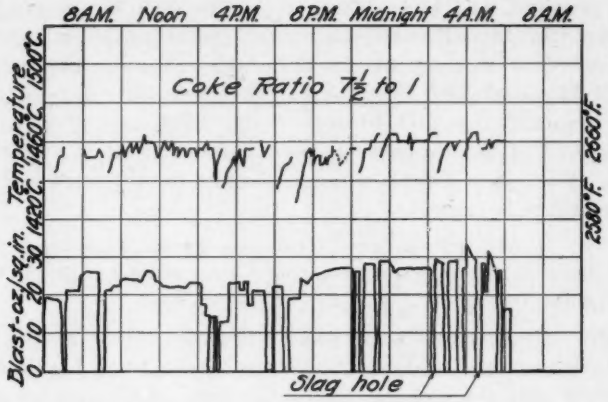

Fig. 3—Cold-Blast Cupola. 24-Hour Heat with Melting Ratio of Approximately 18 Tons Per Hour.

Comparison of Cold and Hot Blast Performance

12. To illustrate the relative performance of the cupolas before and after the installation of the hot-blast device, we have selected two long heats and have illustrated by means of the graph the progress of the campaign.

13. In Fig. 3 it will be noted that the cold-blast cupola, running on a ratio of 7½ to 1 coke in order to produce the 18

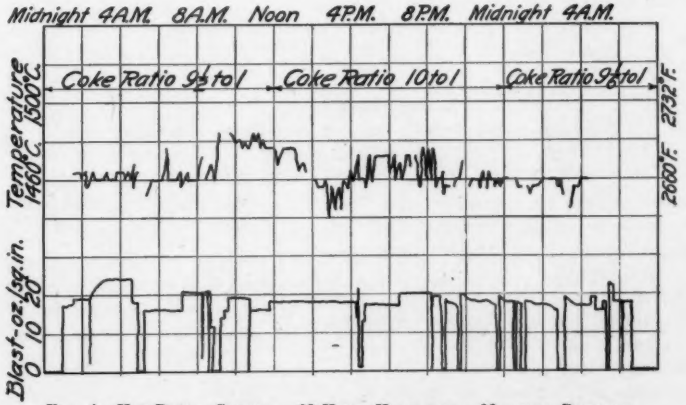

Fig. 4—Hot-Blast Cupola. 29-Hour Heat with Melting Rate of Approximately 20 Tons Per Hour.

tons required, had to be blown at a blast well in excess of 20 ounces. In fact, the average would probably approximate 24 ounces. The temperature in the meanwhile was hanging between 1450 and 1460 degs. Cent. (2642 and 2660 degs. Fahr.), with frequent dips to 1440 degs. Cent. (2624 degs. Fahr.), and in the case of two considerable periods dropped below 1430 degs. Cent. (2606 degs. Fahr.), which is too low for the work and one ladle had to be pigged.

14. It will also be noted that, due to the high blast pressure after 20 hours, a slag hole blew out and the new one only ran two hours before it also had to be replaced.

15. Turning to Fig. 4, which illustrates a heat on the hot-blast cupola, the coke ratio being from 9½ to 10 to 1, it will be observed that the melting rate of 20 tons (approximately two tons better than the cold-blast heat) was easily obtained with a blast pressure of 20 ounces or lower. In fact, the average for the heat probably would be 19 ounces.

16. The temperature here shows a decidedly better average, hanging well over the 1460 degs. Cent. (2660 degs. Fahr.) line, except for one hour—from 3:00 to 4:00 P. M. Here the two pyrometer readers, who read alternately, seem to be unable to agree, the average being about 1450 degs. Cent. (2642 degs. Fahr.) against a minimum of 1440 degs. Cent. (2624 degs. Fahr.). One ladle, after a 30-minute shutdown at 3:00 A. M., again read below 1450 degrees, but the iron quickly pulled up and reached 1460 degrees on the second ladle.

Table 1

COMPARISON OF COLD-BLAST AND HOT-BLAST OPERATION FOR SIX-MONTH PERIOD.

	Cold blast.	Hot blast.
Ratio of iron to coke	7.1 to 1	10.4 to 1
Average no. of pipe cast per shift	386	501
Total delays charged to iron, approximate hrs.	55.5	4.5
No. times cold iron reported	7	1
No. times iron reported slow with no actual delay	22	3
Average blast pressure	20 oz.	14 oz.
Average melting rate per hour	20 tons	25 tons
Average length of heat	12 hrs.	18 hrs.

Six-Month Record of Smooth Operation

17. A record of the six months immediately preceding the installation of the hot blast, and for the six months immediately following the completion of the hot blast installation, is shown in Table 1.

18. The figures of Table 1 show beyond a doubt the smoothness of operation obtained by the use of the hot blast. Troubles from bridging and consequent increasing of blast pressure change from a serious problem to a minor worry.

19. Temperatures which, with the cold blast, were constantly dipping below the danger side are easily maintained at the proper point with the hot blast, and even the dips are still in the region of good iron. While the blast temperature in this type of installation will not average over 300 degs. Fahr.—in fact, in cold weather does not run over 275 degs. Fahr.—it is believed that the point of maximum benefit is the boiling point of water, 212 degs. Fahr., and that after that the increase is linearly with the temperature.

20. It will be conceded that if the cupola blast were heated to the ignition point of the coke — in the neighborhood of 1100 degs. Fahr.—no bridging would be likely to occur, and that the blast pressures could be increased tremendously. This is not feasible in this type of operation, although we believe that any heat of six hours or over should be run on the hot blast.

DISCUSSION

R. S. MacPherran:[1] Mr. MacKenzie, in the operation of this cupola, do you notice any change with the cupola drop? Is the operation more uniform with the hot blast?

J. T. MacKenzie: I think Fig. 1 of the paper shows that. I purposely selected two heats in which the cupola was more or less mistreated by being forced to shut down frequently because of the shop operation, and the smoothness of operation on the hot-blast cupola will be noted as compared with the cold blast, although the hot-blast cupola ran five hours more than the cold blast.

[1] Chief Chemist, Allis-Chalmers Mfg. Co., Milwaukee.

M. SKLOVSKY:[2] Mr. MacKenzie, you state that the preheaters you use in the cupolas are gray iron. Where do they generally burn out—near the bottom?

J. T. MACKENZIE: No, the castings failed by cracking. The severity of the treatment is that in the back side of the casting it is quite cool, especially at the start, and the heat is applied on the front. When we tried a white iron made with 3 per cent chrome, it cracked on the first heat.

JOHN SHAW:[3] How does Mr. MacKenzie take care of the growth of these castings? In the blowing down, one gets a temperature that will lead each time to a continual growth. I note that there is a connection that allows expansion in the pipe, but I should think the brick work would have been pushed up due to growth.

J. T. MACKENZIE: It will be noted that the life is only approximately 75 heats. As a matter of fact, the castings do fail from growth. The back side is cracked, and once this occurs the crack runs around to the front in the course of time. However, by using the ingot mold iron, which is soft and flexible, the casting will yield on the back side to a maximum degree.

JOHN SHAW: I should have thought the casting would have grown at least 20 per cent in 25 heats.

J. T. MACKENZIE: The brick above are iron brick, and if they lift they cause no trouble.

A. L. BOEGEHOLD:[4] In Table 1 the temperature that was obtained is given as 1460 degs. Cent., or about 2660 degs. Fahr. It is my impression that that temperature could be obtained with the cold-blast cupola with a 9½ coke ratio. Is that correct?

J. T. MACKENZIE: I believe this could be done, especially if one is permitted to run the cupola to suit the cupola instead of the shop.

F. G. SEFING:[5] What temperatures were obtained at the tuyeres on the hot blast. Did I understand correctly that they were about 300 degrees? Also, were the gas analyses taken over the charge in both the hot-blast and the cold-blast runs?

J. T. MACKENZIE: The average temperature of the blast is given in the paper. We have made a few gas analyses, and the average carbon monoxide content is about 12 per cent. I do not think there is much difference between the gas content of the hot blast and the cold blast, but gas analysis on the cupola is so erratic a procedure, on account of the difficulty of getting an average sample, that we do not find much usefulness in it. Close to the wall, 18 per cent carbon dioxide is obtained; in the middle, 18 per cent carbon monoxide. Consequently it is a problem to know where to take the analysis.

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[2] Chief Engineer, Deere & Co., Moline, Ill.
[3] Southsea, England.
[4] Metallurgist, General Motors Research Laboratory, Detroit.
[5] Metallurgist, Michigan State College, East Lansing, Mich.

Factors Which Influence the Surface Quality of Gray Iron Castings

By W. G. Reichert* and D. Woolley,† Elizabethport, N. J.

Abstract

As the quality of the surface of the castings produced is one of the major problems of any foundry, the authors of this paper conducted a series of investigations to determine the influence of varying sand conditions on the face of a casting. A special pattern was designed and sands of A. F. A. grain classes and clay content classes 1E, 1F, 2E, 2F, 3E, 3F, 4E and 4F tried out under varying conditions of grain fineness, moisture content, mold hardness, sea coal additions, increase in clay content, method of ramming, pouring temperature and fluidity of the metal. In the investigation, the variables were changed one at a time and the resulting surface appearance noted. The conclusions were that grain size and moisture content are the main factors which influence the surface quality.

1. The quality of surface of the castings produced is one of the major problems confronting all foundrymen, and the reasons for this are obvious. From the standpoint of economy in manufacture, the production of a casting with a smooth surface is an object worth attaining because of the elimination or reduction of the expense of grinding and polishing operations. From the standpoint of marketing the finished product, the sales value of a smooth casting is higher than that of one with a rough surface, because it is more pleasing in appearance and, therefore, more acceptable to the customer.

* Metallurgical Engineer, Singer Mfg. Co.
† Foundry Superintendent, Singer Mfg. Co.

PURPOSE OF INVESTIGATION

2. If, in the manufacture of castings, a good surface is desired, it is necessary that the sand used to produce this surface have suitable physical properties. It is the purpose of this paper to show to what degree the variations in physical properties of the sand affect the surface of the castings. The character of the iron influences the quality of the surface, and this also has been considered.

3. The grade, character and condition of the sand used are very closely associated with the quality of the surface; in order to control the surface, it is essential to determine the relative importance of the molding sand variables which influence it. The temperature and fluidity of the metal have an influence on the surface quality, but to a much smaller degree.

4. In order to obtain definite information on these various factors, a special pattern was designed for this investigation, and we have found a flat casting to be most suitable for this purpose. In order that the actual surface of the casting produced may be shown to the best advantage, the air pressure was reduced to 40 lbs. and the castings were sandblasted with a pulverized silica sand of which 80.0 per cent passes a 140-mesh sieve.

5. A record of the surface was made by taking full-sized photographs of the castings, but to economize space we have shown only a section of these photographs.

PROCEDURE FOLLOWED IN INVESTIGATION

6. In order to arrive at any definite conclusions as to the extent to which certain factors influence the surface of the casting, it was necessary to establish definite constants and variables. These are indicated below:

Constants

(1) The design of the casting.
(2) Parting medium.
(3) The distribution of the sand and bond.
(4) The composition of iron.

Variable Factors

(1) Grain fineness.
(2) Moisture content.

(3) Mold hardness.
(4) Sea coal additions.
(5) Increase in the clay content.
(6) Method of ramming the mold.
(7) Pouring temperature and fluidity of the metal.

Type of Sand Used

7. Typical molding sands of different grade classifications were used, consisting of eight grades of sand defined as A. F. A. grade numbers approximately 1E, 1F, 2E, 2F, 3E, 3F, 4E and 4F. Tables 1 and 2 give the grade and physical properties of these sands.

8. Fig. 1, *A*, *B*, *C*, and *D* (50x magnification), illustrates the character of the sand grains.

Type of Molding Press

9. All molds referred to in this paper, with the exception of those indicated under Fig. 13, page 22, were made with a hydraulic molding press. The machine consists essentially of three

Table 1

Physical Properties of Molding Sands.

A. F. A. Grade No.	Moisture per cent ±0.1.	Tensile strength, lbs. per sq. in.	Permeability.	Dry compressive strength.
1 E	4.5	0.458	12	9
1 E	5.5	0.541	13	16
1 E	6.5	0.481	11	25
1 E	7.5	0.432	10	29
1 F	6.5	0.772	9	37
2 E	5.5	0.550	26	15
2 E	6.5	0.493	25	26
2 E	7.5	0.450	24	32
2 F	6.5	0.796	17	40
3 E	4.5	0.519	32	7
3 E	5.5	0.584	38	14
3 E	6.5	0.552	36	28
3 E	7.5	0.478	35	36
3 F	6.5	0.821	29	39
4 E	6.5	0.488	64	33
4 F	6.5	0.921	51	45

Table 2

FINENESS TEST OF SANDS

U. S. Standard sieves.	A. F. A. Grade Classification Nos. Approximate 1E	1F	2E	2F	3E	3F	4E	4F
6	...	...	...	...	...	...	...	...
12	...	...	...	...	...	...	0.2	0.2
20	0.1	0.1	0.2	0.2	0.1	0.1	0.4	0.3
30	0.2	0.1	0.5	0.3	0.4	0.3	0.9	0.8
40	0.7	0.8	0.9	0.9	1.1	1.2	1.2	1.0
50	0.9	0.2	1.0	1.2	2.0	1.8	2.5	2.9
70	1.2	1.1	5.7	5.1	20.6	19.0	46.6	43.7
100	2.6	2.2	6.7	6.2	14.6	13.5	16.5	15.8
140	12.3	11.1	14.9	14.1	18.3	17.0	9.0	8.1
200	23.2	21.9	20.5	19.6	13.7	13.0	6.0	5.2
270	19.8	18.8	16.8	15.9	4.2	4.2	1.8	1.7
Pan	29.0	28.0	22.0	21.5	13.8	13.3	4.6	4.3
Clay substance	10.0	15.7	10.8	15.0	11.2	16.6	10.3	16.0

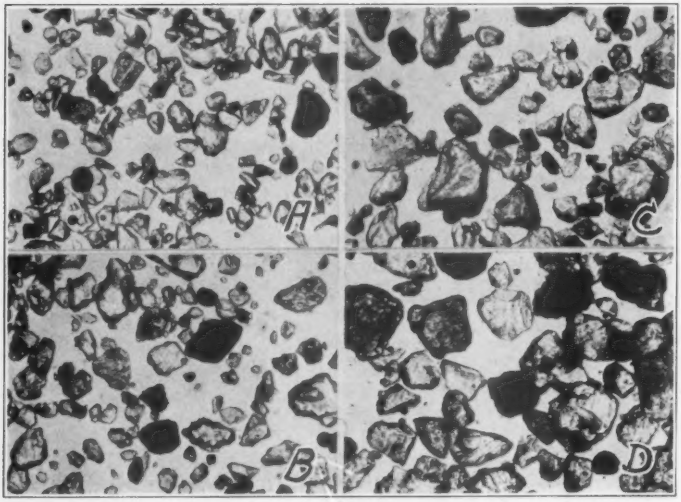

FIG. 1—SAND GRAINS FROM MOLDING SANDS OF VARYING A. F. A. GRADE CLASSES. MAGNIFICATION 50 X.

A: No. 1E SAND.
B: No. 2E SAND.
C: No. 3E SAND.
D: No. 4E SAND.

parts: (a) A lower or movable section consisting of a hydraulic cylinder and piston to which is attached a platen, (b) a swinging section or fixture in which is contained the pattern mounted on a plate, and (c) an upper or stationary section.

10. The flask is placed upon the swinging section, filled with sand and then swung in between the lower movable section and the upper fixed section. The pressure then is applied, and the piston and platen force the pattern into the sand-filled flask. When the pressure is released, the pattern plate recedes and the mold is removed from the lower section.

Design of the Casting

11. A special pattern, consisting of two flat, round disks, was adopted for this investigation, as illustrated in Figure 2. The cross-section of this casting conforms closely with a large amount of the product produced in the foundry where this investigation was made.

12. The entire mold was made in the cope, using wedge gates,

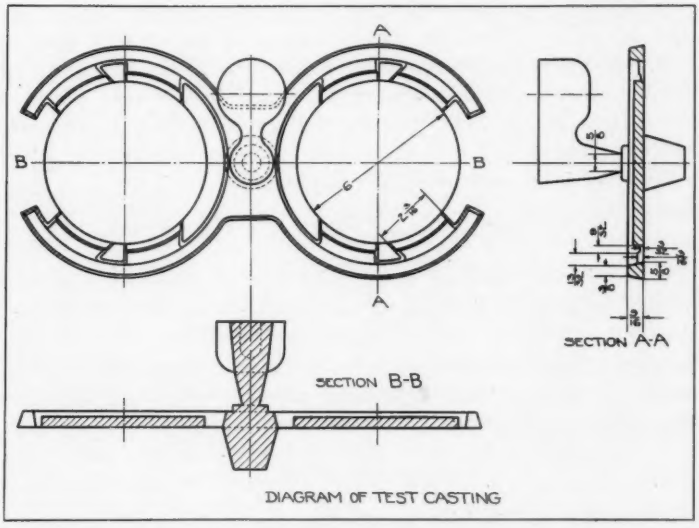

Fig. 2—Diagram of Test Casting.

and the iron entering the mold was choked at the sprue. A pouring basin was added as illustrated in Fig. 2, in order to maintain a constant ferrostatic pressure on the metal.

13. All characteristic surfaces produced in this investigation are relative, and they should be so interpreted. Surfaces corresponding to those indicated will not be produced on all types of castings, but the relation of the results should be the same.

Parting Medium

14. The function of a parting is to obtain a separation of the molding sand from the pattern plate after the mold has been formed, and any agent which repels or rejects water will be successful in accomplishing this purpose.

15. Heat is the most economical parting medium for small work. It is especially applicable where a high production schedule is required, and was used for that purpose in this investigation. Heat is advantageous to use in an investigation of this nature because there is then no possibility of introducing any foreign materials which may influence the character of the surface produced.

16. The molding sands were in contact with the heated pattern for only 35 seconds, and the temperature of each pattern plate was maintained between 80 and 90 degs. Fahr. measured by thermometers using mercury wells located in different parts of the pattern plates. The mercury wells were $\frac{3}{8}$ inch in diameter and approximately 1 inch deep, and the temperatures were taken before and after each mold was made.

Distribution of Sand and Bond

17. Each grade of sand used in this investigation was mulled for five minutes in order to obtain an even distribution of the sand and bond. All molding sands in these experiments were handled entirely by hand in order to prevent any possible balling action of the sand that might occur through mechanical handling and which would influence the results.

Composition of the Iron

18. The composition of the iron was maintained within the following limits:

Silicon, per cent	2.74 -2.83
Manganese, per cent	0.48 -0.52
Sulphur, per cent	0.128-0.137
Phosphorus, per cent	0.582-0.612
Total Carbon, per cent	3.50 -3.60

19. The photomicrograph of Fig. 3 shows the character of the iron on a ½-inch section, having a Brinell hardness at the center of 160.

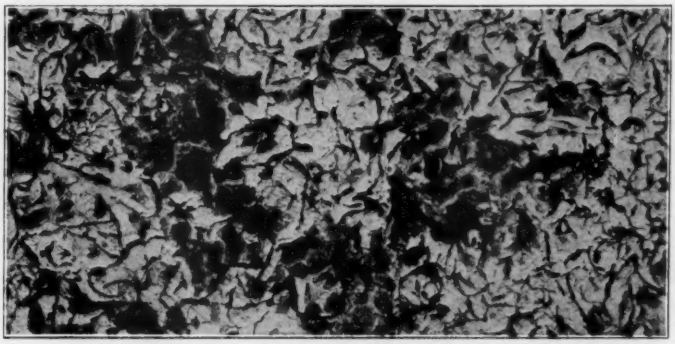

FIG. 3—PHOTOMICROGRAPH OF CAST IRON, ½-INCH SECTION. BRINELL HARDNESS 160. ETCHED WITH 5 PER CENT NITAL. X 150, WITH 14-MM. OBJECTIVE.

Mold Hardness

20. The hardness of the molds was maintained within narrow limits throughout these tests. The hardness in the different sections of the mold, with the exception of Group 7, paragraph 51, varied between 0.055 and 0.065 inch as measured with our mold-hardness testing device.

21. This hardness tester consists of a 1-kilogram weight attached to a ½-inch diameter ball and arranged so that the weight may be released by a lever at the side of the instrument. An Ames dial gage measures the depth of the impression of the ball in thousandths of an inch.

22. The operation is as follows: The instrument is placed on the mold cavity and the side lever released. This allows the

½-inch ball to penetrate the sand under a load of 1 kilogram, and the depth of penetration is indicated on the Ames dial gage.

INVESTIGATION OF THE VARIABLE FACTORS

Group 1—Grain Fineness.

23. In order to determine the influence of the grain fineness on the surface quality of gray iron castings, molds were made with four different types of sand, having A. F. A. grain fineness classification numbers of 1E, 2E, 3E and 4E.

24. The moisture content of the above sands was 6.5 ± 0.1 per cent, and the temperature of the iron entering the mold was 2500 ± 10 degs. Fahr. in every instance.

25. Fig. 4 illustrates the characteristic surface produced by each of the four different grain fineness classification numbers indicated in paragraph 23.

26. It is readily apparent that the character of the surface produced is closely associated with the grade test, and the photographs show the extent to which the surface quality is influenced. As the size of the sand grains decreases, the surface of the casting is improved, due to the smaller percentage of voids.

Group 2—Moisture Content.

27. For this purpose molds were made of sands having A. F. A. grain fineness classification Nos. 1E, 2E and 3E, and each of the sands used in making the molds contained 4.5, 5.5, 6.5 and 7.5 ± 0.1 per cent moisture. The temperature of the metal entering the mold was 2500 ± 10 degs. Fahr. The variations in moisture content noted above are easily possible in the foundry, and it was believed that this difference in moisture would show variations in the surface quality, which could easily occur under ordinary operating conditions.

28. Fig. 5 illustrates the surface produced by a sand of A. F. A. grade classification No. 1E, Fig. 6 by a sand of A. F. A. grade classification 2E, and Fig. 7 by a sand of A. F. A. grade classification 3E with a variable moisture content.

29. From these photographs it will be seen that there is a wide variation in surface quality for each given grain classification number, depending on the moisture content of the sand.

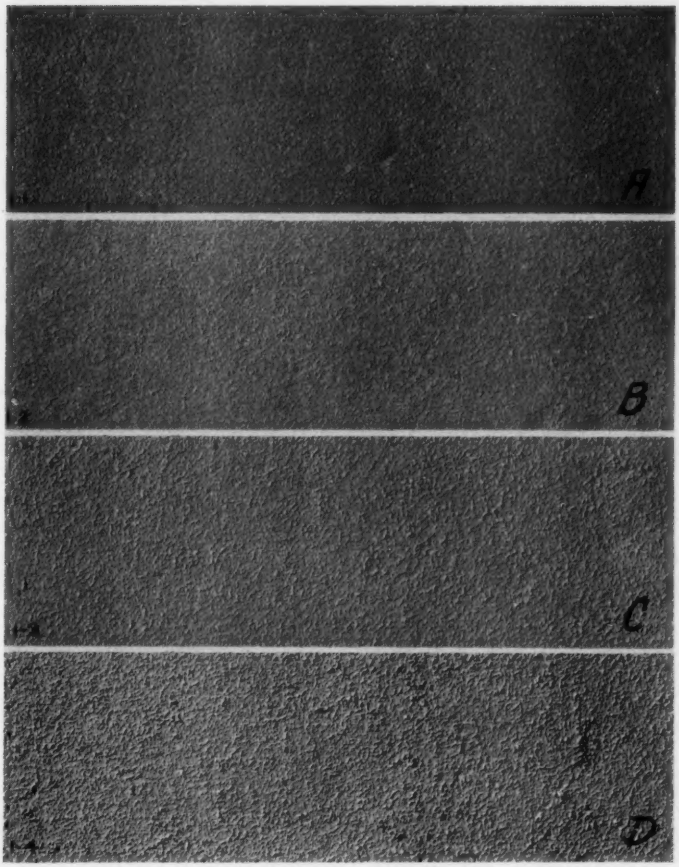

Fig. 4—Surfaces of Gray Iron Castings Produced by Molding Sands of Varying A. F. A. Grain Fineness Classifications.

A: By No. 1E Sand.
B: By No. 2E Sand.
C: By No. 3E Sand.
D: By No. 4E Sand.

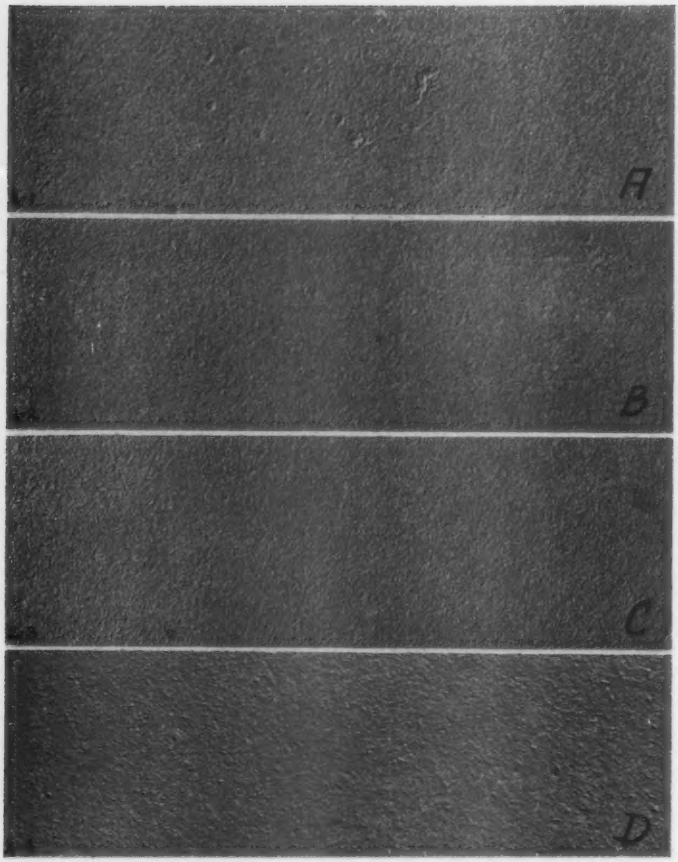

FIG 5.—SURFACES OF GRAY IRON CASTINGS PRODUCED BY MOLDING SANDS HAVING NO. 1E GRAIN FINENESS CLASSIFICATION (A. F. A.) AND WITH VARYING MOISTURE CONTENTS.

A: MOISTURE CONTENT 4.5%. *C:* MOISTURE CONTENT 6.5%.
B: MOISTURE CONTENT 5.5%. *D:* MOISTURE CONTENT 7.5%.

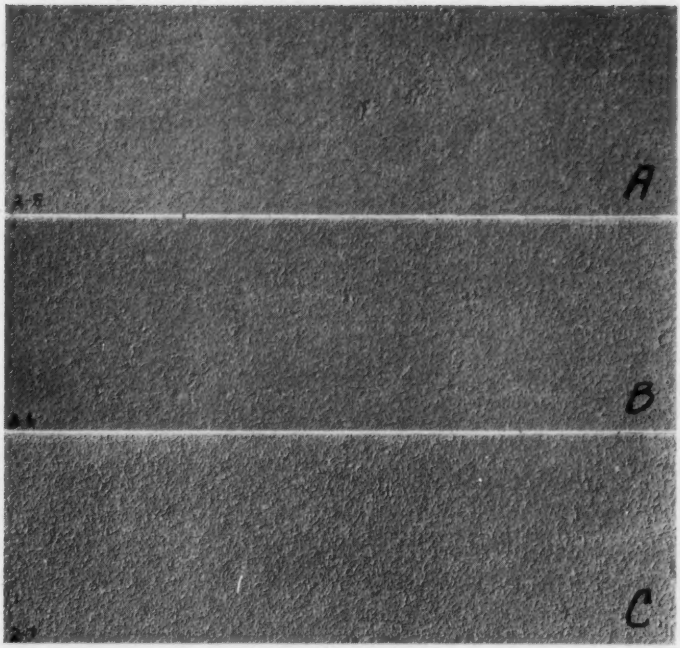

Fig. 6—Surfaces of Gray Iron Castings Produced by Molding Sands Having No. 2E Grain Fineness Classification (A. F. A.) and with Varying Moisture Contents.

A: Moisture Content 5.5%.
B: Moisture Content 6.5%.
C: Moisture Content 7.5%.

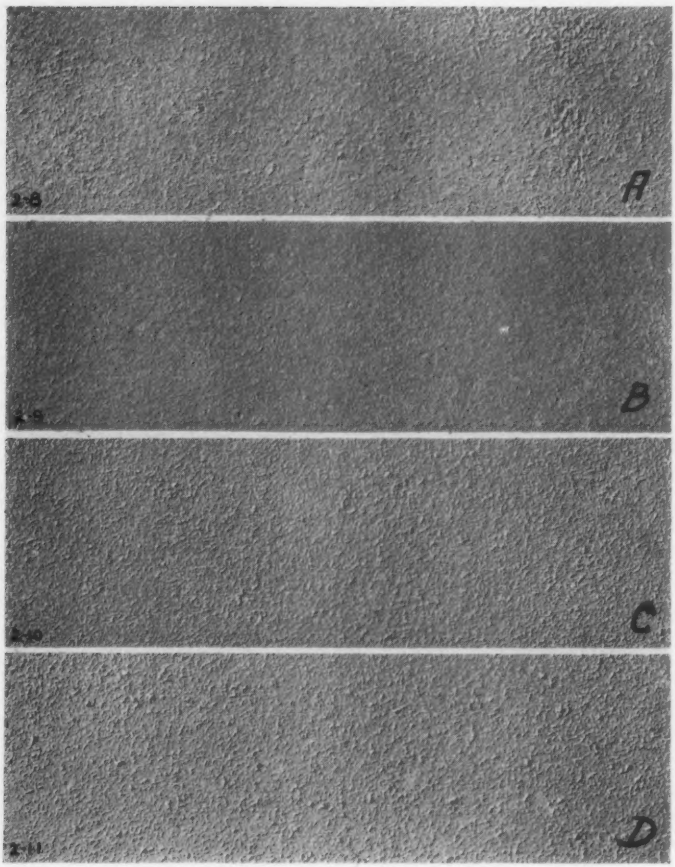

FIG. 7—SURFACES OF GRAY IRON CASTINGS PRODUCED BY MOLDING SANDS HAVING NO. 3E GRAIN FINENESS CLASSIFICATION (A. F. A.) AND WITH VARYING MOISTURE CONTENTS.

A: MOISTURE CONTENT 4.5%. *C:* MOISTURE CONTENT 6.5%.
B: MOISTURE CONTENT 5.5%. *D:* MOISTURE CONTENT 7.5%.

30. The marked effect of moisture is emphasized in the case where a coarse sand of a certain moisture content will produce a better surface than a finer grade of sand having a very large or very small moisture content.

Group 3—Influence of Mold Hardness.

31. All molds in this investigation were made with sands of grade classifications Nos. 1E, 2E and 3E, and the ramming pressure was varied so as to obtain much harder and much softer molds than is the general practice. The hardness of the mold was determined with the mold hardness testing device described in paragraphs 20-22, inclusive.

32. The extremely hard molds using the above mentioned sands gave a depth of impression of only 0.020 to 0.030 inch; the hard molds gave a depth of impression ranging from 0.040 to 0.050 inch—with ordinary or medium ramming the depth of the impression was 0.055 to 0.065 inch; the molds that were rammed soft showed a hardness of 0.080 to 0.090 inch.

33. The temperature of the metal entering the mold in all tests was 2500 ± 10 degs. Fahr., while the moisture content of the sands was 6.5 ± 0.1 per cent.

34. Figs. 8, 9 and 10 illustrate the results obtained from this test.

35. It will be observed that as the mold hardness for each type of sand increases, the surface quality is improved, up to a certain point. Increasing the mold hardness produces a greater flow in the sand and forces the grains closer together, thereby filling the voids and producing a casting possessing a better surface.

36. When the mold is rammed extremely hard with the finer grades of sand, a very poor surface results. We believe this to be due to the low permeability of the hard-rammed mold, which retains the gases in a turbulent condition in the mold and for a longer time, thereby loosening the sand. In the coarser grades of sand, where the permeability is such that the gases can escape at a faster rate even under the hardest ramming, a slight surface improvement is obtained by means of the harder ramming of the mold.

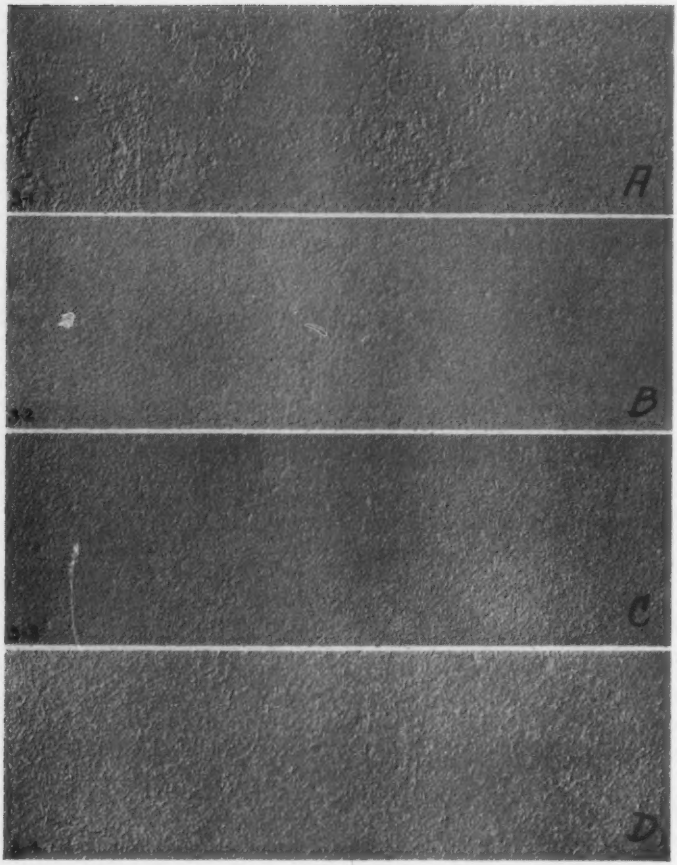

FIG. 8—SURFACES OF GRAY IRON CASTINGS PRODUCED BY RAMMING MOLDING SANDS HAVING NO. 1E GRAIN FINENESS CLASSIFICATION (A. F. A.) WITH VARYING DEGREES OF RAMMING.

A: Very HARD RAMMING, DEPTH OF IMPRESSION .020 TO .030 INCH.
B: HARD RAMMING, DEPTH OF IMPRESSION .040 TO .050 INCH.
C: MEDIUM RAMMING, DEPTH OF IMPRESSION .055 TO .065 INCH.
D: SCYT RAMMING, DEPTH OF IMPRESSION .080 TO .090 INCH.

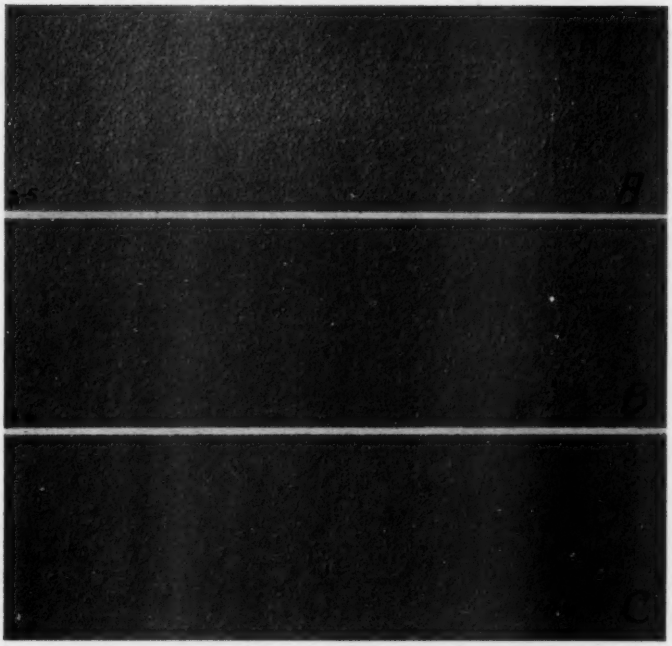

Fig. 9—Surface of Gray Iron Castings Produced by Ramming Molding Sands Having No. 2E Grain Fineness Classification (A. F. A.) with Varying Degrees of Ramming.

A: Hard Ramming, Depth of Impression .040 to .050 Inch.
B: Medium Ramming, Depth of Impression .055 to .065 Inch
C: Soft Ramming, Depth of Impression .080 to .090 Inch.

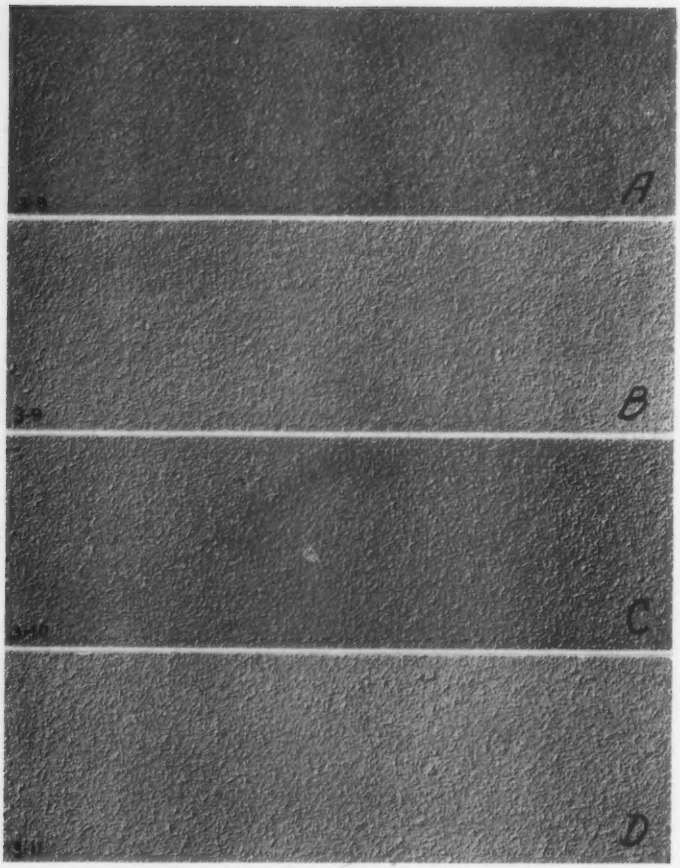

FIG. 10—SURFACES OF GRAY IRON CASTINGS PRODUCED BY RAMMING MOLDING SANDS HAVING NO. 3E GRAIN FINENESS CLASSIFICATION (A. F. A.) WITH VARYING DEGREES OF RAMMING.

A: VERY HARD RAMMING, DEPTH OF IMPRESSION .020 TO .030 INCH.
B: HARD RAMMING, DEPTH OF IMPRESSION .040 TO .050 INCH.
C: MEDIUM RAMMING, DEPTH OF IMPRESSION .055 TO .065 INCH.
D: SOFT RAMMING, DEPTH OF IMPRESSION .080 TO .090 INCH.

Group 4—Sea Coal Additions.

37. It is the general practice in gray iron foundries to add a highly volatile, pulverized bituminous coal—generally termed sea coal—to the sand in order to facilitate cleaning, and it was decided to investigate the effect of sea coal additions on the surface character of the gray iron castings. Molding sands of A. F. A. grain fineness classification Nos. 2E and 3E were used for this purpose, with the addition of 2 per cent and 5 per cent of sea coal by weight to each grade of sand, the analysis of the sea coal used being indicated in Table 3.

Table 3

ANALYSIS OF SEA COAL USED IN TESTS

Fineness Test

U. S. Standard sieves.	Per cent Retained.
70	...
100	1.0
140	8.7
200	15.5
270	10.7
Pan material	64.1

Proximate Analysis

Moisture, per cent	0.98
Volatile matter, per cent	33.92
Fixed carbon, per cent	55.95
Ash, per cent	9.15

38. The temperature of the metal entering the mold was in all cases 2500 $\pm$ 10 degs. Fahr., while the moisture content of the molding sands was maintained at 6.5 $\pm$ 0.1 per cent.

39. Fig. 11, *A* and *B*, illustrate the characteristic surface produced by the addition of 2 per cent and 5 per cent sea coal by weight, respectively, using a molding sand of grain fineness classification number 2E, while Fig. 11, *C* and *D*, illustrate the surface produced by the same sea coal additions, respectively, to sand having a grain fineness classification 3E.

40. A slight improvement in the surface of the casting is obtained by the addition of 2 per cent by weight of sea coal, but when 5 per cent by weight is added a pitted surface or "grape

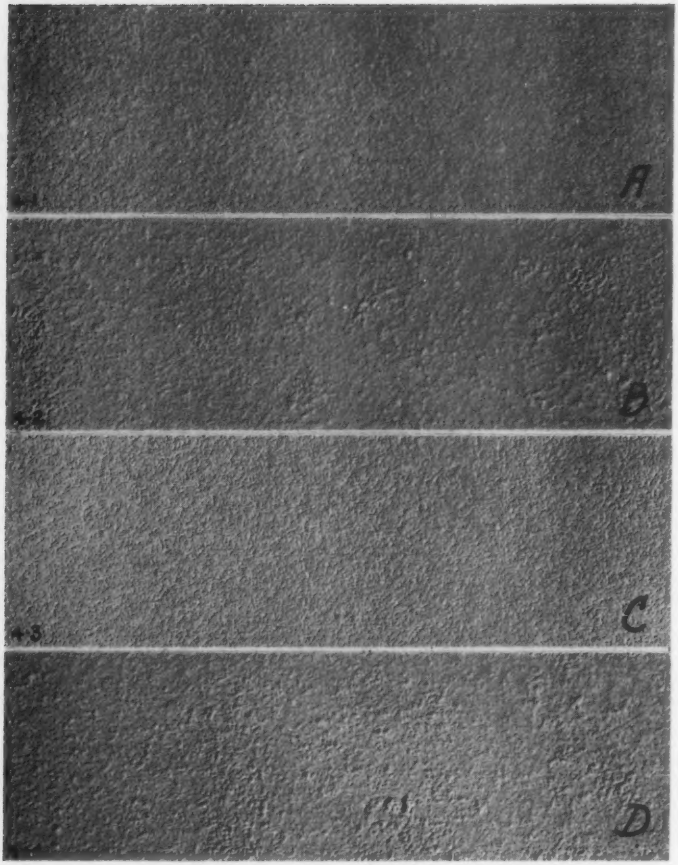

FIG. 11—SURFACES OF GRAY IRON CASTINGS PRODUCED BY ADDING SEA COAL IN VARYING AMOUNTS TO MOLDING SANDS HAVING A. F. A. GRAIN FINENESS CLASSIFICATION NO. 2E OR 3E.

A: NO. 2E SAND, 2 PER CENT SEA COAL BY WEIGHT ADDED.
B: NO. 2E SAND, 5 PER CENT SEA COAL BY WEIGHT ADDED.
C: NO. 3E SAND, 2 PER CENT SEA COAL BY WEIGHT ADDED.
D: NO. 3E SAND, 5 PER CENT SEA COAL BY WEIGHT ADDED.

vine'' effect (which is undesirable) is produced. The results obtained should not be taken to indicate that 5 per cent of sea coal by weight produces pitted surfaces under all conditions, because the effect of the amount of sea coal added to sands used in making different types of castings will vary, depending upon the temperature of the iron, the character of the sand and the type of casting produced.

41. For very light castings, sea coal is not required to facilitate cleaning. We also find that its use in any amount does not materially improve the surface of the castings, providing a suitable sand is used, while, when it is used in excess, it is detrimental to the surface.

Group 5—Increase in Clay Content.

42. In order to determine the effect produced by an increased clay content on the surface quality of gray iron castings, 6 per cent of a white pulverized clay was added to the four grades of sand (1E, 2E, 3E and 4E) previously described in this investigation, and mulled for ten minutes in a Simpson No. 5 mulling machine. The temperature of the metal entering the molds was in all cases 2500 ± 10 degs. Fahr., and the moisture content of the sand 6.5 ± 0.1 per cent.

43. Fig. 12 shows the surfaces produced by the above molding sands.

44. It will be observed that the surface quality produced for each type of sand is not quite as good as those shown in Fig. 4, where the lower clay content was used.

45. As indicated in the data of Table 1, a higher clay content molding sand has a low permeability and does not allow the gases to escape as easily as do molding sands of a lower clay content. Before using molding sands of high clay content, careful thought and consideration should be given the matter, for an excess quantity of clay may materially affect both the surface quality and losses. The surface produced is dependent on the flow of the sand and the distribution of the clay and fine sand grains.

Group 6—Method of Ramming the Mold.

46. All large foundries have different types of machines for molding operations, and these differ from each other in the man-

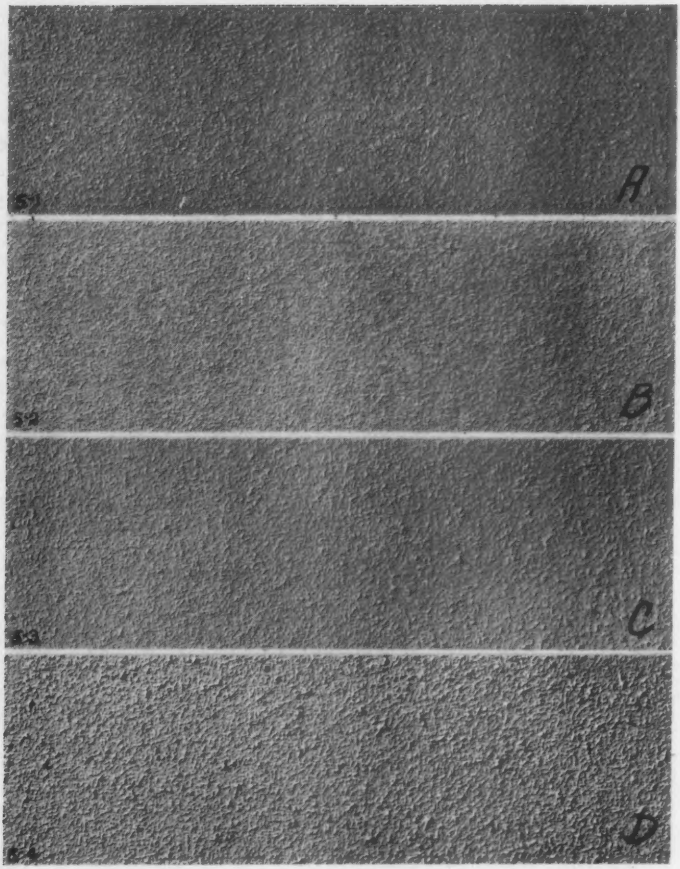

FIG. 12—SURFACES OF GRAY IRON CASTINGS PRODUCED BY MOLDING SANDS OF VARYING A. F. A. CLAY CONTENT CLASSIFICATIONS.

A: No. 1F SAND.
B: No. 2F SAND.
C: No. 3F SAND.
D: No. 4F SAND.

ner in which the sand is rammed into the mold. Different machines are used to accommodate the various types of work.

47. In order to determine the surface quality produced by a bottom and top squeeze machine, the pattern was transferred to a Tabor molding press, a top-squeeze machine where the pressure is applied on the side opposite the mold cavity. Molds were made with sands of grain fineness classification 1E, 2E, 3E and 4E.

48. The condition of the sand, temperature of the iron, mold hardness, etc., were the same as indicated under Group 1, paragraph 23, and these surfaces were compared with those of Group 1 which were made under identical conditions with the hydraulic molding press.

49. Fig. 13 indicates the surface of the castings produced using the above-mentioned sands.

50. On comparing Fig. 13 with Fig. 4, it will be observed that for all practical purposes the surface quality of the castings produced by the use of these machines for each of the different grades of molding used, and under the conditions specified, is identical. The surface of the castings produced when using a pressure-type machine for either top or bottom squeezing is identical because the flow of the sand is the same in both cases, all other conditions remaining constant.

Group 7—Pouring Temperature and Fluidity of the Metal.

51. Whenever metal is handled in the foundry, a loss in temperature and fluidity occurs due to the length of time taken for the handling of the metal from the main spout of the cupola to the pouring of it into the molds. We have determined the effect produced by a variation of 200 degs. Fahr. in the iron temperature, as this variation may occur in normal foundry operations.

52. We have used molding sands of grain fineness classification Nos. 1E, 2E and 3E and have varied the pouring temperature on each of these sands, allowing the metal to enter the mold at 2400, 2500 and 2600 degs. Fahr. with a variance of $\pm$ 10 degs. Fahr. The temperature readings throughout these experiments were obtained with the aid of an optical pyrometer.

53. The moisture content of each grade of sand was maintained at 6.5 $\pm$ 0.1 per cent. To serve as a check on the temperature as indicated by the optical pyrometer, a fluidity test spiral

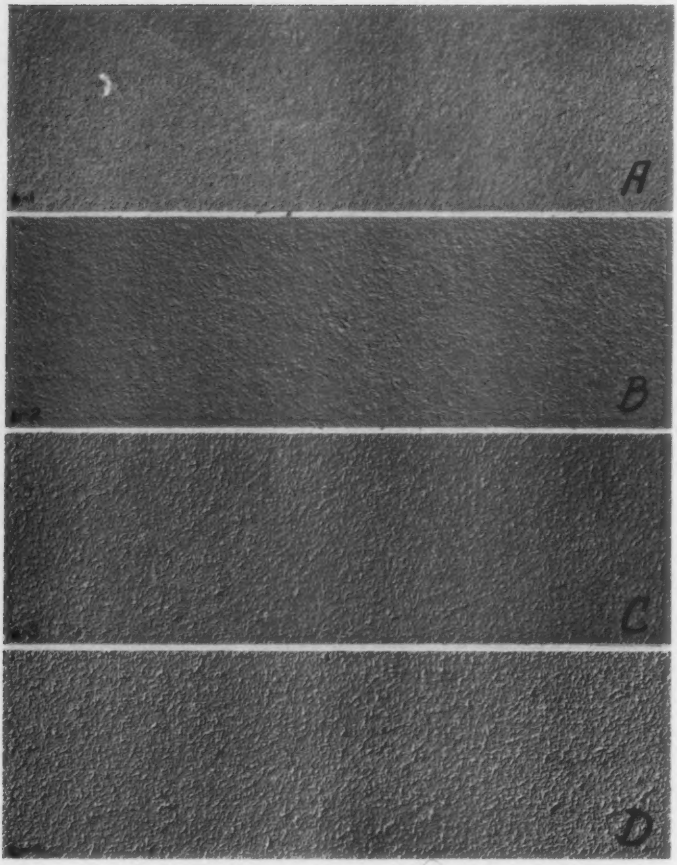

FIG. 13—SURFACES OF GRAY IRON CASTINGS PRODUCED BY RAMMING MOLDING SANDS OF VARYING A. F. A. GRAIN FINENESS CLASSIFICATIONS IN TABOR MOLDING PRESS.

A: No. 1E SAND.
B: No. 2E SAND.
C: No. 3E SAND.
D: No. 4E SAND.

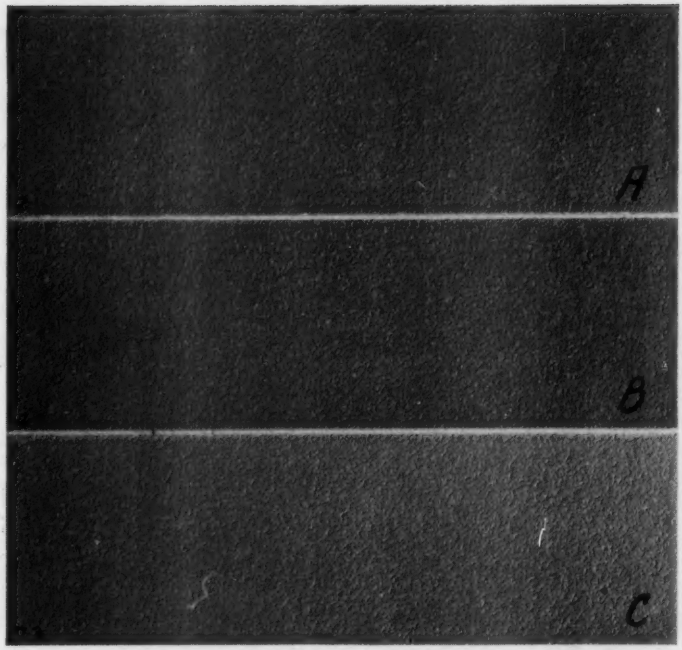

Fig. 14—Surfaces of Gray Iron Castings Produced by Molding Sands Having No. 1E Grain Fineness Classification (A. F. A.) and at Varying Degrees of Pouring Temperature.

A: Poured at 2400 Degs. Fahr.
B: Poured at 2500 Degs. Fahr.
C: Poured at 2600 Degs. Fahr.

also has been included to show the fluidity at the various temperatures indicated.

54. This fluidity test piece was developed by Curry[1] and consists in running the iron through a V-shaped mold having the form of a spiral. Notches are placed at equal distances at the top of the mold and the results expressed in relation to the distance the iron has traveled over these notches.

55. The metal is poured into a basin and runs into a reservoir located beneath the mold. The mold is constructed in such

[1] Curry, C., *Test Bars to Establish the Fluidity Qualities of Cast Iron.* TRANSACTIONS A. F. A. (1927), vol. 35, pp. 289-305, cut on p. 301.

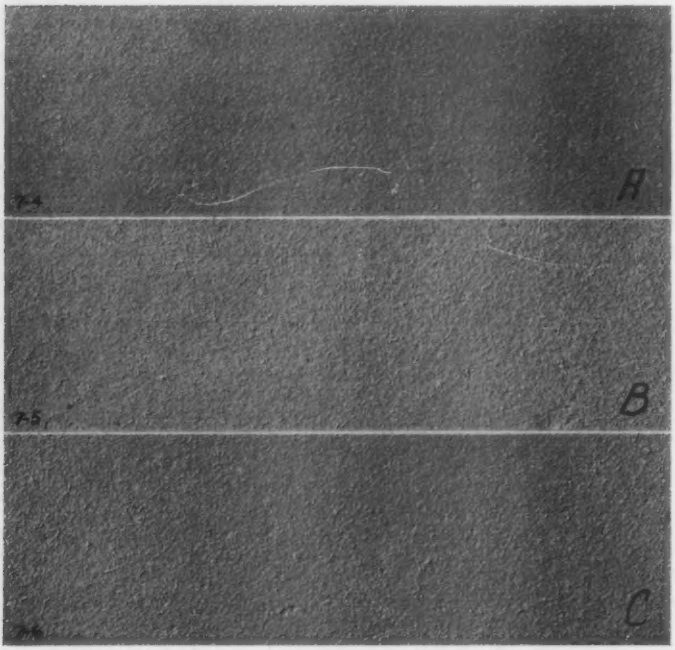

FIG. 15—SURFACES OF GRAY IRON CASTINGS PRODUCED BY MOLDING SANDS HAVING NO. 2E GRAIN FINENESS CLASSIFICATION (A. F. A.) AND AT VARYING DEGREES OF POURING TEMPERATURE.

A: POURED AT 2400 DEGS. FAHR.
B: POURED AT 2500 DEGS. FAHR.
C: POURED AT 2600 DEGS. FAHR.

a manner that the metal runs through the mold spiral only after filling the inlet basin and reservoir. The fluidity tests at 2400, 2500 and 2600 degs. Fahr. are 10.0, 12.5 and 15.0 notches, respectively.

56. Figs. 14, 15, 16 and 17 indicate the surfaces produced for the above variations in temperature, using sands of grade classification 1E, 2E, 3E and 4E.

57. It will be observed from these photographs that, with the use of the finer grades of sand, there appears to be only a slight effect on the surface quality of the castings with a 200-degs. Fahr. difference in temperature. However, as the grain

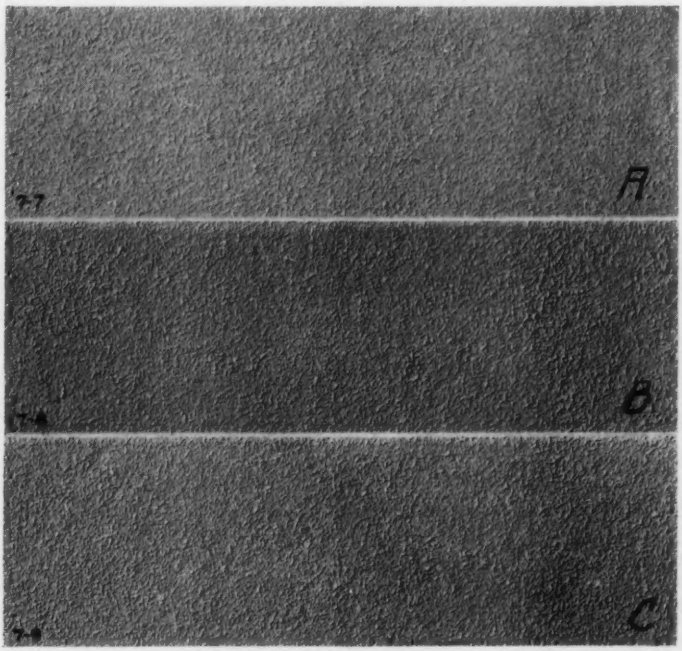

Fig. 16—Surfaces of Gray Iron Castings Produced by Molding Sands Having No. 3E Grain Fineness Classification (A. F. A.) and at Varying Degrees of Pouring Temperature.

A: Poured at 2400 Degs. Fahr.
B: Poured at 2500 Degs. Fahr.
C: Poured at 2600 Degs. Fahr.

size of the molding sand increases, the influence of the temperature and fluidity of the iron becomes more apparent, and this is especially true at the higher pouring temperatures. This surface effect probably is due to the fact that the coarser grades of sands have a larger percentage of voids.

58. The higher the temperature at which the metal is poured, the greater will be the tendency for the metal to fill the voids between the sand grains at the mold cavity. This is due to the greater penetration of the metal into the large voids.

59. In all the above experiments the lower pouring temper-

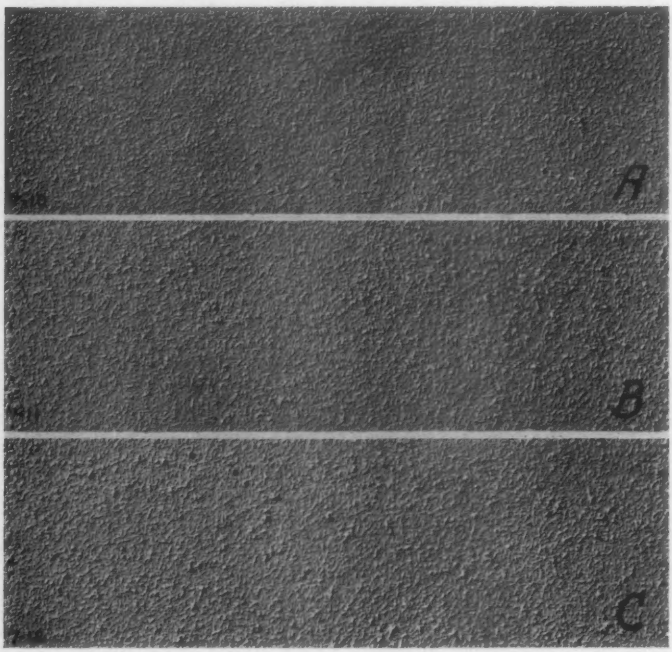

FIG. 17—SURFACES OF GRAY IRON CASTINGS PRODUCED BY MOLDING SANDS HAVING NO. 4E GRAIN FINENESS CLASSIFICATION (A. F. A.) AND AT VARYING DEGREES OF POURING TEMPERATURE.

A: POURED AT 2400 DEGS. FAHR.
B: POURED AT 2500 DEGS. FAHR.
C: POURED AT 2600 DEGS. FAHR.

atures have produced the most satisfactory surface quality castings, all other conditions remaining constant.

CONCLUSION

60. Our conclusion from this investigation is that the grain size and moisture content of the molding sand are the main factors which influence the surface quality of a casting. In selecting a sand for a casting where the surface is important, we must consider these two factors in conjunction with the physical qualities required by the particular mold.

61. The other variables also have a definite effect which should be recognized, but their effects are of less importance.

DISCUSSION

A. SELBERT:[1] The author mentions that, in ramming the molds, he fills up the flask with sand and presses the pattern down into the flask. What is the advantage of pressing it from the top instead of from the bottom?

W. G. REICHERT: As the paper brought out, there is no advantage in applying pressure from the top or at the mold cavity, so far as the surface quality is concerned. There is a definite advantage, however, in pressing it at the mold cavity because the permeability at the top of the mold is greater than at the mold cavity, thereby allowing the gases to escape more easily. If the sand is pressed from the top, the result will be as great a hardness at this point as at the mold cavity; consequently, the gases do not escape as easily.

A. M. PHILION:[2] Will the author explain a little more clearly what is meant by the statement that the permeability of the sand is less at the top of the mold than at the bottom, due to the pushing of the pattern up into the sand?

W. G. REICHERT: That refers to the method of making the mold. The pattern is forced into the sand; consequently, the permeability at the mold cavity will be less than at the top of the mold.

[1] Foundry Superintendent, Foote Bros. Gear & Machine Co., Chicago.
[2] Apprenticeship Foreman, Studebaker Corp., South Bend, Ind.

A. M. PHILION: Then is not the permeability naturally going to be less at the bottom than at the top?

W. G. REICHERT: Yes, it will be less at the bottom than at the top.

A. M. PHILION: If the permeability is less at the bottom next to the flat face of the casting, why should it not be more difficult for the gases to escape, since the permeability next to the casting is what controls the escape of the gas, unless vents are so arranged as to handle its removal?

W. G. REICHERT: To a certain extent, that is true. I believe that in facing a mold the permeability depends on just how much sand is used for facing. If only a very small amount of sand is used for facing, the permeability is controlled to a large extent by the heap sand.

A. M. PHILION: I am rather dubious about that point. It seems to me that the permeability of the sand immediately adjacent to the top of a flat casting is the factor which controls the escape of the gas. With a low permeability facing, blows most certainly will result, no matter how open the backing sand may be—unless, of course, other means are provided for removing the gases.

W. G. REICHERT: If just sufficient facing sand is used to cover the pattern surface, I believe that permeability is due mainly to the backing sand. That has been my experience.

R. F. HARRINGTON:[3] Mr. Philion, have you ever had occasion to measure the permeability on the surface of a mold when the mold has been leaded or graphited? If you have, you probably have found that permeability was absolutely zero. Also, in dry sand work, if an impervious mass of blacking or graphite is put over the surface of the mold, the permeability again is practically zero.

I think we must substantiate the fact that the question of permeability back of the surface is very important.

A. M. PHILION: It most certainly is very important. However, the point I am making is that the gas cannot get away rapidly enough if a low permeability facing is rammed over the casting and no other means are provided for removing the gases from the mold.

R. F. HARRINGTON: I think we must admit that most of the gas with which we are concerned is back of the surface of the mold or in the sand between the surface of the mold and the flask.

A. M. PHILION: I believe that to be true only in the case of castings made without cores; but when one considers automotive or similar castings which are heavily cored, we must admit that the gases coming from the inside of the casting, emanating from the binders in the cores, are those which require the most rapid removal. It is my opinion that so long as the permeability of the backing sand is greater than that of the sand adjacent to the mold cavity, no matter if it be only one point greater, the gases resulting from pouring an uncored casting will readily escape.

ARNOLD LENZ:[4] Regarding the gases escaping from the cores, we have

[3] Metallurgist, Hunt-Spiller Mfg. Corp., Boston.
[4] Manager, Gray Iron Foundry, Chevrolet Motor Co., Saginaw, Mich.

found that if gases from the core are allowed to get into the mold, trouble results anyhow. I think Mr. Reichert is right in saying that permeability back of the facing is what counts and not the permeability on the face, because we get a surface that necessarily has to be low in permeability, and the more cores in a mold, the more are the cores apt to reabsorb their own gases back and out through the core vent and not out to the mold surface.

A. M. PHILION: It is my belief that the reabsorption of gases by hot cores, to any appreciable degree, is a physical impossibility. In a recent issue of *The Foundry* there was an article in which the gas conditions resulting from the moisture in the sand were discussed fully.

The point was brought out by the author of that article—I thought it a good point and should like to present it at this time—that as soon as a casting is poured, the moisture converted to steam immediately charges through the sand toward the outer surface, and as soon as it is far enough removed from the hot section of the mold near the metal, it condenses and forms a film all around the casting, thereby effecting the building up of a back pressure. Beyond that film of condensate the permeability does not mean a thing. Unless vents have been properly arranged, it was shown that blows most certainly will result.

I merely quote this article to show a verification of my theory that a backing sand of a very high permeability is not always a necessity, if the mold is vented properly.

WRITTEN REPLY BY AUTHOR

W. G. REICHERT: I believe that the paper indicated quite clearly the effect of top and bottom squeezing on the surface finish of the castings. Quoting from the paper, paragraph 50: "The surface of the castings produced when using a pressure-type machine for either top or bottom squeezing is identical because the flow of the sand is the same in both cases, all other conditions remaining constant."

With reference to Mr. Philion's remarks regarding the difference in permeability at the mold cavity and at the top of the mold, I wish to state that, while it is not within the scope of this paper to give a detailed discussion of the construction of the machine, I do feel that this point should be amplified in order to enlighten the readers of this discussion.

In the majority of experiments indicated in this paper, molds were made by placing a definite amount of sand in the flask and forcing the pattern into this sand to a predetermined depth depending upon the results desired. It has been found that when this method of ramming is used, the permeability at the mold cavity is less than it is at the top of the mold. As the top of the mold is approached, the permeability gradually increases, thereby allowing the gases to escape more easily.

On the other hand, if the backing sand has a lower permeability than the sand forming the mold cavity, the escape of the gases through the mold

is considerably reduced, and frequently a sufficient back pressure is developed to cause the casting to blow.

Finally, I wish to emphasize the fact that, in using fine sands where just sufficient facing sand is required to cover the pattern, a good permeability on the backing sand is essential in order to allow the rapid escape of the gases.

Melting of Gray and Malleable Iron in the Indirect-Arc Furnace

By J. C. Bennett* and J. H. Vogel,† York, Pa.

Abstract

An electric furnace was installed to melt both malleable iron and special gray-iron castings. Details of the operation of the furnace are given. Temperatures are checked by an optical pyrometer. Fracture test bars are used to check the iron. Flexibility in making various mixtures is given as a decided advantage of the electric furnace. Data of the iron qualities are discussed. Costs of operation are outlined, these being divided into groups the most important of which are (a) power, (b) refractories, (c) labor and (d) electrodes.

1. Cold melt production of gray and malleable white irons in the indirect-arc electric furnace has been successful elsewhere, and it is our purpose to describe this operation as practiced by us and the characteristics of castings produced by it for pressure work.

Details of Furnace Used

2. The furnace used in our malleable foundry is of 1-ton capacity, of the rocking type (Fig. 1), made by the Detroit Electrice Furnace Co.

Shell and Lining

3. The steel shell of the furnace has an outside diameter of 5 feet 9 inches and an overall length of 5 feet, while the corresponding inside dimensions are 3 feet 8 inches, and 3 feet, respectively. The shell is lined with a 4-inch thickness of a well-

*Metallurgist, York Ice Machinery Corp.
†Assistant Superintendent, York Ice Machinery Corp.

known brand of insulating brick on which the refractory lining is laid. This latter consists of a special brand of molded refractory brick which is 8 inches in thickness.

Temperatures

4. The temperature reached by furnace walls often exceeds 3000 degs. Fahr., the temperature of the walls exceeding the pouring temperatures of the iron by at least 200 degrees. The tem-

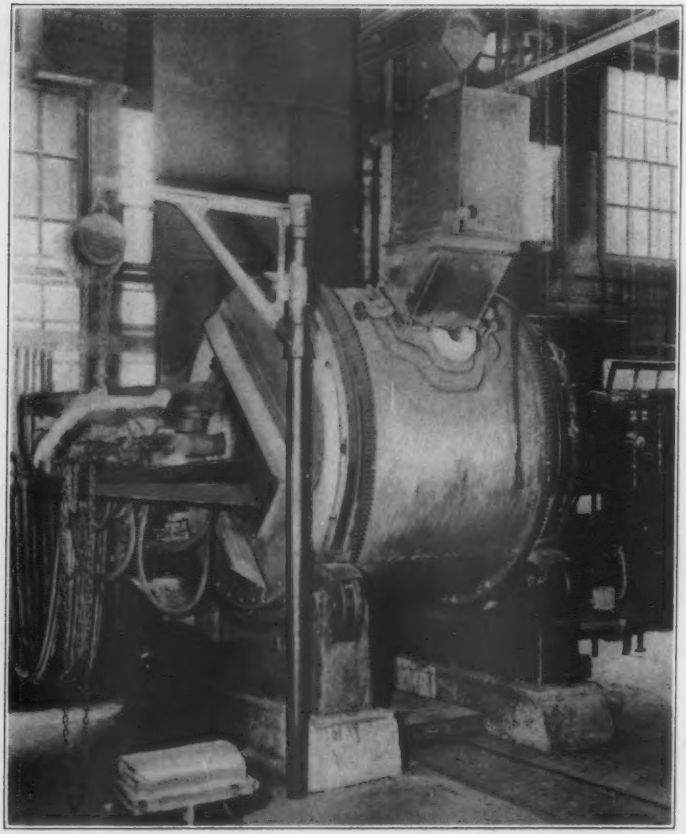

FIG. 1—VIEW OF ELECTRIC FURNACE INSTALLATION, SHOWING ELECTRIC CRANE PLACING CHARGING BUCKET IN CHARGING POSITION.

perature generated by the arc has been estimated at 6400 degs. Fahr.

Electrodes

5. The carbon electrodes are 5 inches in diameter and 3½ feet in length, and are joined by graphite nipples. The electrode clamps are water-cooled and, in addition, there is a copper coil around each electrode adjacent to the furnace walls to keep the electrodes beyond this point as cool as possible.

Power Input Control

6. The power input is automatically controlled to regulate the speed of melting, being maintained at the desired rate by automatic adjustment of the distance between the electrodes. This is done by means of a reversing motor which moves the electrodes together should the input fall below, or moves them apart should the input exceed the desired rate.

Method of Charging

7. The charge of raw material is placed in buckets and dropped in the door of the furnace, as shown in Fig. 1. An electric crane lifts the bucket, which is discharged at the bottom.

Operation and Checking

8. In starting the furnace the power is applied and the furnace rocked through an arc of about 45 degrees during the first 25 minutes of the heat, or until the charge is partly melted. Then the rocking arc is gradually increased to 160 degrees and the furnace is operated through this arc until ready to pour.

9. When the power consumption has reached the point where pouring is imminent, a reading of the temperature of the furnace walls is taken with an optical pyrometer, precaution being taken that the reading is made on the side or roof removed from the arc. If the temperature is not sufficiently high, the arc again is applied until the desired heat is obtained. In addition, the metal at the spout is also checked for temperature.

10. Prior to pouring the heat a fracture bar (shown in Fig. 2), the thickness of which tapers from ¾ inch down to ⅛ inch,

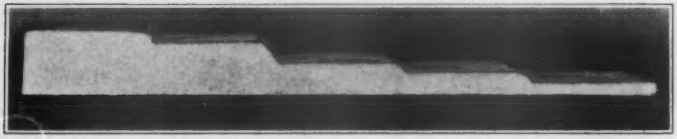

FIG. 2—FRACTURE TEST BAR. THICKNESS AT HEAVY END ¾ INCH; AT THIN END ⅛ INCH.

is poured, cooled in water and broken. This determines whether or not any correction must be made to prevent excessive hardness in the castings. The necessity for this check and subsequent correction is due to the variation in the borings used as raw material.

11. The metal is tapped into a geared ladle holding about 700 lbs. of iron, from which the floor work is poured, while snap flasks are poured from hand ladles fed by the large geared ladle. The time from charging the furnace to pouring the metal ranges from 80 to 85 minutes and, in less than two hours from the time the arc is applied, the heat has been tapped, the next charge introduced and the arc started again.

ELECTRIC FURNACE REPORT—YORK ICE MACHINERY CORPORATION

DATE 7/1/30 FURNACE No. 1 OPERATOR Ehlers REPORT No. 113

		1	2	3	4	5	6	7	8	9	10
Day Heat Number		147	148	149	150	151	152				
Lining Heat Number		5:00	7:00	9:00	10:55	12:55	2:40				
Time Arc On		5:00	7:00	9:00	10:55	12:55	2:40				
Time Started Rocking		0	0	0	0	0	0				
K.W. Hrs. Started Rocking		6:30	8:30	10:30	12:15	2:10	4:10				
Time Arc Off		600	570	560	550	540	580				
K.W. Hrs. - Total		2840	2830	2830	2830	2820	2900				
Metal Temperature °F											
Composition and Analysis of Charge	Borings	1200		1200	1200	1200					
	Sprue	800	840	800	800	800	2000				
	Pig		1100								
	Steel		60	15		15	20				
	Nickel			36		36					
	Ferro Sil.	16		16	16	16					
	Ferro Phos.										
Total Wt. of Charge		2016	2000	2067	2016	2067	2020				
Type Castings Poured		Small Fittings	Piston Rings	Manifolds	Small Fittings	Manifolds	Conn. Rods				

Remarks: #2 Heat Piston Rings
#6 " Malleable Iron

Copy to { Cost Dept.
Metallurgical Dept.
Gen. Supt's. Office
Malleable Fdy.

FIG. 3—REPRESENTATIVE ELECTRIC FURNACE DAILY REPORT.

Advantages of Electric Furnace

12. One of the chief advantages of the electric furnace is its flexibility, or the ease by which the chemical and physical properties of the iron can be changed at will. For example, during one day's run of six heats we have poured as many as four different kinds of iron, namely, ordinary gray iron for small pressure castings, low-carbon gray iron with 2 per cent nickel for manifolds, high-phosphorus iron for piston rings and, finally, malleable iron for large connecting rods. A representative daily furnace report is shown in Fig. 3.

13. A second advantage of the electric furnace lies in the fact that the cheapest kind of raw material can be used. Our normal gray iron charge consists of 60 per cent cast-iron borings and 40 per cent scrap and sprue. The necessary ferrosilicon is added to prevent undue hardness and, as indicated above, for certain classes of complicated thin-walled castings, steel is added to close the grain and 2 per cent nickel is used to prevent chilled sections.

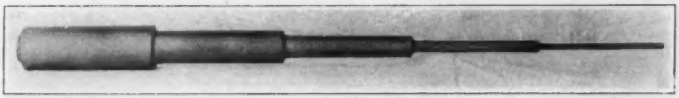

FIG. 4—TELESCOPIC TEST BAR. EACH SECTION IS 6 INCHES LONG. DIAMETER RANGES FROM 2 INCHES TO ¼ INCH.

PROPERTIES OF GRAY IRON OBTAINED

14. The properties of our gray iron heats can best be indicated by a report covering a number of test pieces cast from the same ladle of electric-furnace iron.

15. A telescopic, fracture test piece is shown in Fig. 4. The sections are 6 inches long and range from ¼ inch to 2 inches in diameter. The fractures through the middle of these sections are shown in Fig. 5. Photomicrographs at 100 and 1000 diameters, respectively, were taken at the center of each section and are shown in Figs. 6, 7 and 8.

Transverse Tests

16. Six A. S. T. M. 1¼-in. arbitration bars were cast and broken for transverse strength, with the results shown in Table 1.

Tensile Tests

17. Coupons taken from these bars were then turned to the standard A. S. T. M. requirements for tensile testing and broken, the results being given in Table 2.

Chemical Analyses.

18. An analysis was made from the broken test pieces, and the report submitted shows the data of Table 3.

19. The samples from which these results were obtained were taken from a heat for production castings and are representative

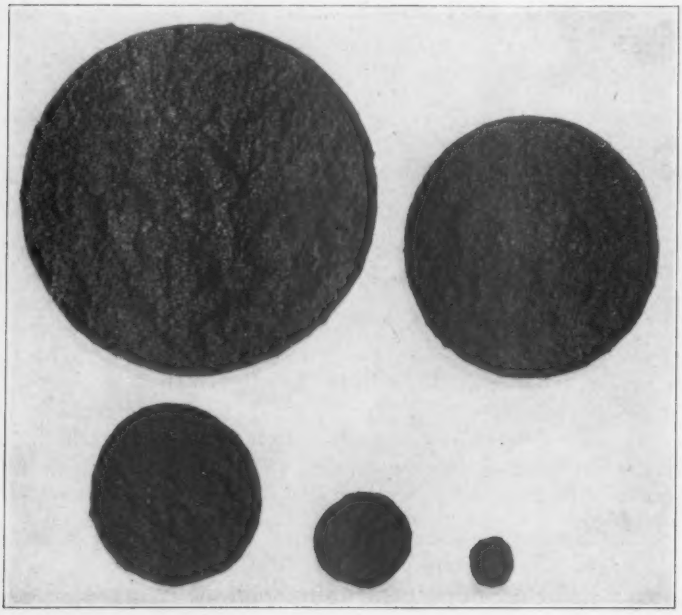

FIG. 5—FRACTURES OF GRAY IRON CAST AS TELESCOPIC BAR OF FIG. 4. DIAMETER OF SECTIONS, 2 INCHES, 1½ INCHES, 1 INCH, ½ INCH AND ¼ INCH, RESPECTIVELY.

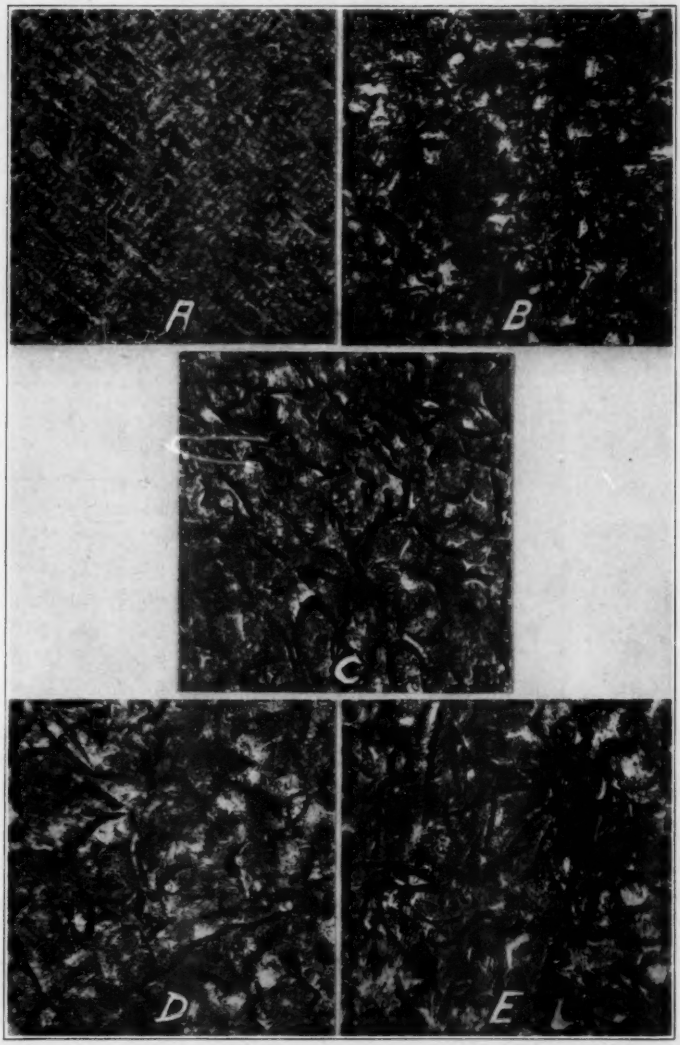

FIG. 6—PHOTOMICROGRAPHS OF FRACTURES OF BAR SHOWN IN FIG. 5. ETCHED WITH PICRIC ACID SOLUTION IN ALCOHOL. X 100. *A*: ¼-INCH SECTION. *B*: ½-INCH SECTION. *C*: 1-INCH SECTION. *D*: 1½-INCH SECTION. *E*: 2-INCH SECTION.

FIG. 7—PHOTOMICROGRAPHS OF FRACTURES OF BAR SHOWN IN FIG. 5. ETCHED WITH PICRIC ACID SOLUTION IN ALCOHOL. X 1000. *A*: ¼-INCH SECTION. *B*: ½-INCH SECTION. *C*: 1-INCH SECTION.

of results which are obtained in our standard fitting heats. Far greater physical properties can be obtained if desired, but it must be remembered that, due to the fact that practically all our castings made are for pressure work, tightness is more desirable than excessive strength.

MALLEABLE IRON PRODUCTION

20. For the production of large, malleable-iron connecting rods, we have found the electric furnace to be an indispensable part of our equipment. The charge of metal as introduced into the furnace for these castings consists of 99 per cent malleable-iron sprues (our own accumulation) and 1 per cent steel scrap. This proportion keeps the analysis and quality of the iron constant.

21. Low-carbon iron requires high pouring temperatures, due to its tendency to freeze quickly. In our product the pouring temperature at the spout must range between 2900 and 3000 degs. Fahr. for sound castings. Through ladle transfer and the distance the iron is transported, the heat loss is about 200 degrees.

22. The high temperatures obtained at the mold give the iron fluidity, thus allowing proper feeding through the risers and permitting the escape of gas. The annealing cycle applied to this

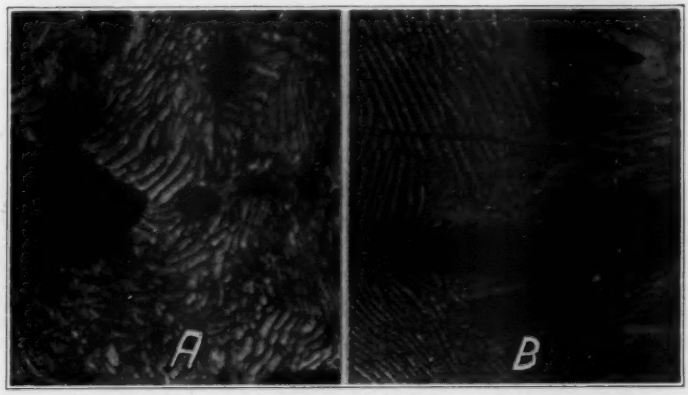

FIG. 8—PHOTOMICROGRAPHS OF FRACTURES OF BAR SHOWN IN FIG. 5. ETCHED WITH PICRIC ACID SOLUTION IN ALCOHOL. X 1000. *A*: 1½-INCH SECTION SHOWN AS *D* IN FIG. 6. *B*: 2-INCH SECTION SHOWN AS *E* IN FIG. 6.

Table 1

TRANSVERSE TESTS ON 6 A. S. T. M. ARBITRATION BARS

Bar No.	Brinell at center.	Diam. of bar, in inches.	Deflection, in inches	Transverse strength, in lbs.
1	207	1.270	0.135	4510
2	201	1.234	0.156	4640
3	207	1.237	0.153	4620
4	201	1.236	0.130	4210
5	197	1.270	0.132	4330
6	207	1.265	0.128	4270

Table 2

TENSILE TESTS ON BARS OF TABLE 1

Bar No.	Diam. of bar, in inches.	Tensile strength, in lbs. per sq. in.
1	0.8	33,000
2	0.8	34,800
3	0.8	32,000
4	0.8	32,600
5	0.8	32,600
6	0.8	29,600

Table 3

CHEMICAL ANALYSIS OF BROKEN TEST PIECES FROM BARS OF TABLE 1

	Per cent.
Silicon	2.52
Sulphur	0.045
Phosphorus	0.207
Manganese	0.60
Nickel	1.93
Total carbon	3.22
Free carbon	2.68
Combined carbon	0.54

malleable is that which is standard for malleable iron, namely, 1600 degs. Fahr. for 60 hours and a cooling rate of about 4 degrees per hour until 1200 degs. Fahr. is reached, when the oven doors are opened and the castings are allowed to cool to room temperature.

23. The successful performance of the connecting rods necessitates inspection of both white and annealed castings. The greatest cross-section of these rods is about three square inches,

FIG. 9—VARIOUS VALVE AND FITTINGS CASTINGS POURED IN ELECTRIC FURNACE IRON.

and this section must be absolutely free from primary graphite. The annealed castings machine readily and take on a good finish, while the physical properties of the iron are far better than those of air-furnace iron of the same analysis.

24. The report covering 25 heats of our electric-furnace malleable iron, as given by the Malleable Iron Research Institute, show the following averages:

Tensile strength, lbs. per sq. in.	57,480
Yield point, lbs. per sq. in.	38,330
Elongation, per cent in 2 in.	22.1

25. The laboratory reports the average white iron analysis of these heats as follows:

Silicon, per cent	1.10
Sulphur, per cent	0.043
Phosphorus, per cent	0.14
Manganese, per cent	0.29
Carbon, per cent	2.10

26. The products of our electric furnace vary greatly in weight and section, ranging in weight from 2 ounces to 300 lbs.

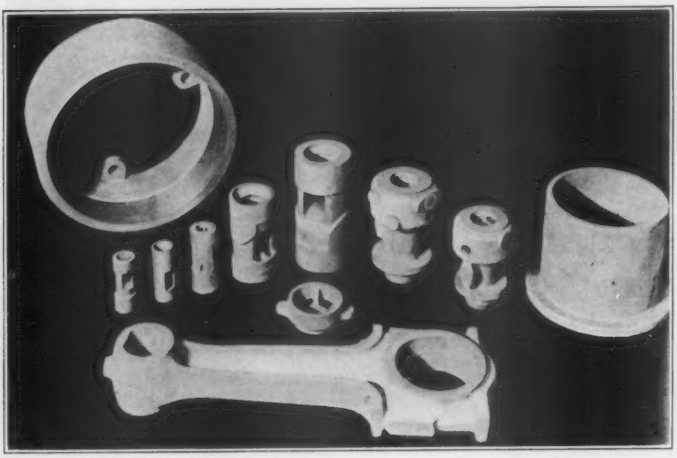

FIG. 10—PISTONS, CYLINDERS AND PISTON-RING POT CASTINGS POURED IN ELECTRIC-FURNACE IRON. CONNECTING ROD SHOWN IS OF MALLEABLE IRON.

and from ¼ inch to 2 inches in thickness. Fig. 9 shows an assortment of valves and fittings. Fig. 10 shows a grouping of pistons, cylinders and piston-ring pots, together with a valve disk and a malleable-iron connecting rod. Fig. 11 shows four of our manifold castings.

COSTS

27. The indirect-arc electric furnace is not noted for its ability to melt iron more cheaply than any other unit. However, because of the possibility of using the cheapest raw material avail-

able, the cost of the iron at the spout can be brought down to a figure which compares very favorably with the cost of iron when melted in an air furnace or a cupola.

28. The data on costs given below were accumulated over a three-month period during which time 300 heats were run. Subsequent checking has shown that these figures, although they may vary slightly, are in the main representative for our operation. All costs given are per ton of iron poured and are based on a melting loss of 2 per cent, which we have established as correct by careful checking.

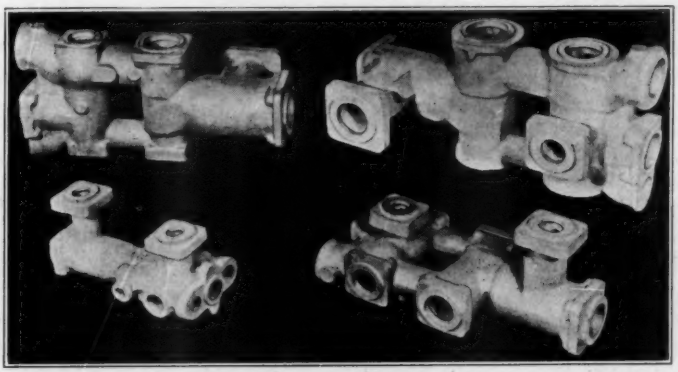

FIG. 11—MANIFOLD CASTINGS POURED IN ELECTRIC-FURNACE IRON.

Power Costs

29. The greatest cost per ton is chargeable to power. Our average kilowatt-hour consumption is 610 per ton at a cost of 1.3 cents per kilowatt-hour, or $7.93 per ton of iron. This may seem high, inasmuch as 600 kilowatt-hours per ton usually is considered a good average figure. However, it must be remembered that this 610 kilowatt-hours includes all power used for preheating, etc.

30. Normally, the daily average is 580 kilowatt-hours per ton, the first heat of the morning running approximately 610 while the last heat of the day usually drops to 550. Malleable

heats average slightly greater kilowatt-hour consumption, probably due to the higher pouring temperature (usually 580 in a hot furnace). Our normal power input is at the rate of 400 kilowatts.

Refractories Costs

31. The second cost in order of importance is refractories, our best average cost to date being $2.55 per ton of iron poured. This figure includes all furnace operation expense items which are chargeable to refractories, including the insulating lining, the refractory lining, both material and installation labor and all patching labor and material.

32. During the run on which these cost figures were accumulated, Silocel insulating material, one particular brand of refractory bricks and another brand of patching material were used entirely.

Procedure in Patching Furnace

33. Our method of handling the furnace as regards patching is worthy of mention. Normally the last heat of the week is made on Friday afternoon. As soon as the iron is out, the furnace is turned with the door up, the electrodes removed and the discharge line from a small electric blower (10-in. fan, ¼-h.p. motor) is inserted in one electrode port, the other port being plugged. This blower discharge line has a deflector on the end which forces the air toward the bottom of the furnace. The blower is run continuously until Sunday morning, when the patching is done.

34. Incidentally, we also use this blower to force fresh air into the furnace while the workmen are inside patching. This makes it possible for them to remain in the furnace as long as an hour, whereas 15 minutes was about the limit without the air.

Chipping Out and Applying the Patching.

35. Before applying the patch, all burned material is chipped out with an air hammer, the sides of the remaining walls being under cut as much as possible in order to key in the patch. The patch then is applied approximately ¾ to 1 inch thick and rammed in place with an air hammer.

36. No attempt is made to maintain the original furnace

dimensions by building up the walls, the reason being that the patching material, having practically no bond, will have very little strength unless thoroughly sintered, and apparently the heat does not penetrate a thick patch sufficiently to accomplish this at the back. Consequently, the thick patch breaks out instead of gradually wearing away as the thin, well-fused patch does. Bear in mind that the above applies only to the brand of patching material used in this case. We have found that an entirely different procedure must be adopted for other patching materials.

Drying.

37. After the patching is completed, the furnace is allowed to air dry until Monday morning, or, if the patching has been excessive, a slow coke fire is started at once and kept going until Monday. Monday morning, prior to charging, the furnace walls are heated to 3000 degs. Fahr.

Experience With Patching Materials.

38. We have tried numerous other patching materials with rather poor results, with the exception of one other brand. At the present time we are making a test run using this material, and the preliminary results seem to indicate that it is superior to the other patching materials we have used. This material apparently works best when applied in coatings from 2 to 3 inches thick, and also is recommended for monolithic linings. If this material fulfills its promise we will next try a complete lining of this brand of lining material, applying it directly to the insulating brick.

Roof Failures.

39. As would be expected, the roof of the furnace fails first, inasmuch as it is subjected to the arc without any protection for a longer time than any other portion of the lining. In order to lessen this tendency, we now are operating the furnace upside down at the start of the heat for approximately half the number of heats. In addition to saving the roof, this method of operation also prevents the accumulation of slag on the bottom. In order to prevent electrode breakage due to this procedure, we charge the furnace, roll it over and insert the electrodes with the furnace in the upside-down position.

Determining Status of Lining.

40. In order to determine at any time the status of the lining, we plot a curve showing refractory cost per ton against tons charged. A sample curve is shown in Fig. 12, while Table 4 indicates the method of accumulating the data. As shown, the cost per ton is arrived at by dividing the total lining and patching cost to date by the total tons charged to date.

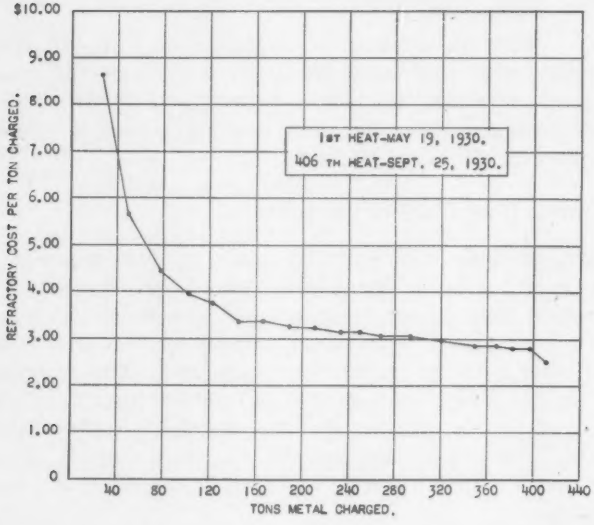

FIG. 12—CURVE SHOWING REFRACTORIES COST PER TON OF IRON CHARGED, FOR 1-TON ELECTRIC FURNACE.

41. This curve, in addition to giving at any time our refractory cost per ton, also indicates the need of relining should this occur before the apparent total failure of the lining. For instance, should the curve rise consistently it indicates that the lining is in such bad shape that the excessive patching costs are increasing the refractory cost per ton. It is, advisable, therefore, to reline even though the lining apparently is good for many more heats.

Table 4

Refractory Cost Per Ton Charged for 1-Ton Electric Furnace

Date	Tons charged to date.	Cost of patch material for week.	Patch labor for week.	Total Patch and lining cost to date.	Refractory cost per ton charged.
May 19—Mon.					
May 23—Fri.	27.5	$41.63	$12.94	$237.05	$8.62
May 26—Mon.					
May 29—Thur.	49.9	38.00	6.00	281.05	5.63
June 2—Mon.					
June 6—Fri.	78.5	60.00	8.00	349.05	4.44
June 10—Tue.					
June 13—Fri.	102	45.00	8.00	402.05	3.94
June 17—Tue.					
June 20—Fri.	123.5	51.15	10.24	463.44	3.75
June 24—Tue.					
June 27—Fri.	145	22.65	4.75	490.84	3.38
June 30—Mon.					
July 3—Thur.	166.4	65.15	9.00	564.99	3.39
July 8—Tue.					
July 11—Fri.	188.8	45.00	10.50	620.49	3.28
July 14—Mon.					
July 18—Fri.	211	52.50	9.00	682.00	3.23
July 22—Tue.					
July 25—Fri.	232.6	37.60	14.25	733.85	3.15
July 29—Tue.					
Aug. 1—Fri.	248.8	46.90	10.00	790.75	3.17
Aug. 4—Mon.					
Aug. 8—Fri.	268.8	30.95	7.75	829.40	3.08
Aug. 11—Mon.					
Aug. 15—Fri.	292.3	61.40	7.75	898.55	3.07
Aug. 18—Mon.					
Aug. 22—Fri.	320	48.30	6.00	952.85	2.97
Aug. 25—Mon.					
Aug. 29—Fri.	349.4	41.65	3.75	998.25	2.85
Sept. 2—Tue.					
Sept. 5—Fri.	368	45.95	10.35	1054.55	2.86
Sept. 8—Mon.					
Sept. 11—Thur.	382.6	15.00	3.45	1073.00	2.80
Sept. 15—Mon.					
Sept. 18—Thur.	396.9	37.65	8.63	1119.28	2.80
Sept. 22—Mon.					
Sept. 25—Thur.	411			1119.28	2.50

Refractories Offer Chance for Further Cost Reductions.

42. The refractory situation is, in our opinion, the one that offers the greatest opportunity for further reduction in the indirect-arc-furnace operating expense. We wish to state, however, that shut-downs due to lining failures are rather rare. If the patching is done carefully and consistently, we have found that a full week's run usually can be obtained. However, to do this it is necessary to repair any spots that are at all doubtful during the regular patching period.

43. At times it has been necessary to make minor repairs to the hot lining, and for this purpose we have had very good results with a well-known brand of cupola patch. Applying this material consists of mixing it with water to a soup-like consistency and pouring it into the bad spots in the lining by means of a long-handled ladle. It would be expected that this material would blow out immediately due to the generation of steam, but such is not the case. It hardens in place and stands up very well.

Electrode Costs

44. The third item of expense is chargeable to electrodes. We average 9.7 lbs. of electrodes per ton, at a cost of $0.1875 per lb., or $1.82 per ton of iron poured.

45. Electrode breakage is practically entirely the result of carelessness in handling the furnace and has been reduced to a minimum in our operation through attention to the condition of port holes and proper manipulation, especially at start of heat.

Labor Costs

46. Our labor cost averages $1.40 per ton of iron poured. One man spends full time on the furnace; a second assists in charging and pouring. Labor cost is high but cannot be materially reduced for one furnace. In case a second furnace were installed, this item would remain practically constant with an attendant reduction in labor cost per ton of approximately 40 per cent.

METHOD OF CHARGING

47. Our method of charging is simple and effective. Bottom-dump buckets holding 700 lbs. are used. These buckets are loaded in the pig iron storage and brought to the furnace by elec-

tric trucks. Prior to charging, a steel funnel is hung on the door bolts and the furnace rotated until the door is in the 45-degree position. The bucket is raised by an electric hoist, moved into position over the funnel and the bottom dropped. With these buckets we can charge one ton metal in less than 5 minutes.

48. This method of charging might appear, on the surface, to be rather hard on the lining; but such is not the case. We have had no lining difficulty which might be remotely blamed on this mechanical charging. However, we always charge borings first so as to cushion as much as possible the blow of the heavier pieces of the charge on the bottom. These buckets are used for all material charged, with the exception of an occasional piece which is too large to go through the bucket opening.

49. Fig. 1 shows the furnace being charged. The bucket is in the charging position over the funnel.

SUMMARY OF COSTS

50. A summary of the above costs is as follows:

Power	$7.93
Refractories	2.55
Electrodes	1.82
Labor	1.40
Interest, depreciation and repairs	2.00
Total	$15.70

51. The total melting cost, therefore, is $15.70 per ton of iron poured, exclusive of supervision and rent.

52. Our normal gray iron charge consists of 60 per cent borings at present market price of $6.50 per ton, and 40 per cent of our own scrap valued at $14.00 per ton. The necessary ferro-silicon averages $1.25 per ton, making a total material cost per ton of $10.81. This brings the total cost per ton at the spout to $26.51, or 1.325 cents per pound.

53. As stated before, it is possible to produce iron at the spout slightly cheaper than this by other methods of melting. However, when the flexibility of the unit is considered, together with the continuous character of the heats and the superior quality of the iron produced, we feel that the advantages are with the electric furnace for a foundry handling the variety and typ of work such as we are producing.

DISCUSSION

MEMBER: Mr. Vogel, have you made any tests using this monolithic lining of the cupola for a complete lining in your electric furnace?

J. H. VOGEL: No, we have not as yet, but we plan on doing so the next time we reline the furnace.

G. OLSON:[1] Mr. Vogel says that he is using 99 per cent malleable scrap and one per cent steel to keep the analysis at a constant figure. We know that some are running air furnaces and some are running cupola malleable iron, and there is quite a variation in analyses of the two irons. How is this being regulated when going out in the open market to buy scrap?

J. H. VOGEL: We do not buy scrap; we use our own. We are running air furnaces on malleable at the same time; consequently, we have enough of our own scrap to supply the electric furnace.

B. G. PARKER:[2] Do you manufacture your own power?

J. H. VOGEL: No.

B. G. PARKER: What does this electric furnace do to your demand charge? I suppose you have a demand charge.

J. H. VOGEL: That is what brings our total power cost up to 1.3c per kilowatt. Power cost alone is only 0.78c per kilowatt.

B. G. PARKER: You penalize your furnace but do not penalize the rest of your shop?

J. H. VOGEL: The average on the remainder of the plant, exclusive of the furnace, also is 1.3c per kilowatt, so that it is not a case of penalizing either. We are now putting a demand limitator on our lines which will work on the furnace and will reduce our kilowatt cost somewhat.

M. J. GREGORY:[3] With your operating costs of $15.70, and when it is possible to put iron in the cupola and melt it at the spout for about $16 (material and labor), how can you compete commercially against a cupola type of iron?

J. H. VOGEL: We could not compete. We have the advantage, however, of continuous iron and also the advantage of special heats when we want them. It must be remembered that our foundry is rather small and that we have quite a variety of work going through it. We absorb all our own castings and do not sell any of them. For that reason we can afford to do this.

M. J. GREGORY: If you were selling them, could you do it? How could the average foundry employ this installation and compete, providing the cupola iron is good iron?

J. H. VOGEL: I do not think it could if the cupola was doing a satisfactory job.

C. H. MORKEN:[4] I would like to call the attention of Mr. Gregory to

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[1]Illinois Malleable Iron Co., Chicago.

[2]President and General Manager, Youngstown Foundry & Machine Co., Youngstown, Ohio.

[3]Factory Manager, Caterpillar Tractor Co., Peoria, Ill.

[4]Foundry Engineer, Detroit Electric Furnace Co., Detroit.

the fact that if he takes the figure of $16—which is what we term the conversion charge—and adds to it the value of the materials used, in more cases than not cupola costs will be equal or better by using the right kind of materials. In other words, let us assume that we will be able to buy borings at approximately $6 or $7 or $8 per ton. Add this to the $16, giving a total cost of approximately $24 a ton in the spout, which compares favorably with most cupola operation.

M. J. GREGORY: That does not answer the question. A price of something like $8 for borings was mentioned, which is a rather high figure at present, and, I believe, a high figure at an average time. However, it is possible to bring down material in the cupola at about $16 at the present time—labor, materials and everything.

C. H. MORKEN: If iron is being brought down at $16, which is beating most cupola operations I have seen recently, on that basis the electric furnace iron will be more expensive.

H. M. LANE:[5] At the Baker-Perkins Co. in Saginaw, Mich., they have one of these furnaces and a cupola. By keeping off the peak load with the furnace so as to keep the demand charge satisfactory, the electric furnace has tied the cupola cost. When they have to get the demand charge against it, they have a little higher cost, but they get enough better metal so that it has more than paid to do this.

On a good many castings the average loss from certain causes is considerable. By using this metal, the losses are cut down, the quality is better and for that reason the electric furnace has been the most economical for their work.

This electric furnace was put in originally as an auxiliary unit. During this past year it has been used on practically all the work of the shop. Some months they have taken no more than one heat in the cupola, and while the furnace is normally called the 700-lb. furnace, it has made castings weighing over a ton.

J. T. MACKENZIE:[6] Mr. Vogel, in Fig. 4 you show a section six inches long, ranging from one-quarter inch to two inches in diameter. Did you run that from the small end or the large end?

J. H. VOGEL: From the large end.

MEMBER: Mr. Vogel, how close can you keep your carbon?

J. H. VOGEL: We correct to prevent chill by addition of ferro-silicon, and while we have a carbon variation it is not sufficient to cause us any trouble. We use only our own borings, incidentally, so we may know fairly well what we are getting back.

MEMBER: What would be your average variation? If you adopt a standard, how close do you maintain it?

J. H. VOGEL: Our average gray iron variation is about 0.1, varying between 2.95 and 3.05. Malleable variation is the same, varying between 2.00 and 2.10.

M. J. GREGORY: I might elaborate just a little further on the ques-

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[5]Consulting Engineer, Detroit.

[6]Metallurgist, American Cast Iron Pipe Co., Birmingham, Ala.

tion of briquetting. In our plant at Peoria, Ill., we have been using some of the materials in the cupola to help bring the cost down.

We take our borings—malleable and cast iron and nickel steel borings, which carry about 3.5 per cent nickel—and briquet them all together. Of course, this makes some difference when one gets down to the material cost.

A. E. HAGEBOECK:[7] Mr. Gregory, from a cost point of view, does the figure you give include interest on investment for your melting department, maintenance, power and all the cost of that department?

M. J. GREGORY: Yes, that takes in everything, even to the extent of running 30 per cent capacity of the investment.

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[7]President, Frank Foundries Corp., Moline, Ill.

Chemical Composition as Employed for Classifying Carbon and Alloy Steels for Castings

By R. A. Bull,* Chicago.

Abstract

The author discusses the present confusing state which exists in regard to designation of various grades of steel castings. It is suggested that a factor which in all probability has been the chief cause of misunderstanding in classifying the product of the steel foundry, lies in the rapidly extended use of castings that might be called "very slightly alloyed." After discussing various phases of the subject, the author advances conclusions as to what should be done and presents as a basis of discussion some specific recommendations as to classifications.

1. It is not surprising that the increasing production of steels for castings, differing in chemical composition from that previously employed to very large extent in making the steel foundry product, should have resulted in conflicting opinions as to where to draw the line between the combination of chemical elements in a typical carbon steel casting and that of the elements in a casting that should be known as a product of alloy steel.

2. The variable extent to which each element is employed in three of the five customarily associated in the composition of steel has led, quite naturally, to divergent ideas regarding limitations for classifying the material as being of the carbon grade, or of one of the alloy grades. Some interesting situations have developed as the result of the absence of an acceptable boundary line, and, in a few cases, troublesome misunderstandings have occurred.

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* Director, Electric Steel Founders' Research Group.

NOTE: This paper was presented and discussed before one of the steel sessions at the 1931 convention of the American Foundrymen's Association.

3. The writer wishes to explain, at the outset, that he adheres to no arbitrary opinion regarding places to draw lines, in differentiation. His purpose in centering attention on the subject is to prompt an interchange of opinions which might lead to general agreement. Such a result unquestionably would be helpful to consumers and, for that and other reasons, advantageous to producers.

4. It may be the difficulty of differentiation that has induced a few manufacturers to describe the metal in steel castings as "common" and "special," rather than as "carbon" and "alloy." This practice has points in its favor, but it possesses disadvantages, one of which is the impression created in the minds of some users that the term "common" identifies a material as having been made without much regard for quality.

5. Of course, the word "uncommon," as the antonym of common, implies the extraordinary. But it is significant, for the purpose now in mind, that there appears to be no word in our language which means something that is usual or ordinary as to the proportions of its component parts, and at the same time is being made or is capable of production with every consideration for care and skill in manufacture.

Confusion Caused by Product Slightly Alloyed

6. A factor that in all probability has been the chief cause for misunderstanding in classifying the product of the steel foundry lies in the rapidly extended use of castings that might be called "very slightly alloyed."

7. The most outstanding example of such a material is steel that is normal as to the content of each element excepting manganese, and containing, very often, about 1.25 per cent of that element. Probably this is the cheapest steel made for castings which belongs, for the present, in what some would consider as "no-man's land," or outside the category of metals usually thought of by many persons when discussing alloy steels in general terms.

8. There are a few steel foundrymen who have maintained that metal of the composition referred to should not be considered as having chemical properties justifying classification among alloy steels for castings. Nevertheless, these producers do not deny the desirability of identifying the material as being different

in important respects, chemically and physically, from the regular grade of steel. Its present importance justifies a definite place in a proper classification.

9. Incidentally, the commercial significance of metal of the kind just mentioned supplies a reason for its separate identification in its own grade of alloy material, so that it may be readily distinguishable from manganese steel of the austenitic variety. It is not very convenient to describe it as pearlitic manganese steel. If we call it medium manganese steel, meaning that it has a content of manganese intermediately between the amount of manganese in regular or common steel, and the amount of that element in Hadfield's manganese steel, some erroneous impressions might be avoided.

10. However, it is the present purpose of the writer, not to propose satisfactory descriptions of any individual variety of alloy steel, but to suggest for debate suitable names and means for applying them to groups of steel into which the metal appears to divide itself.

11. The arguments that have been advanced in some quarters, that metal we have described (incorrectly or not) as of the medium manganese variety should not be considered as an alloy grade, are based on the individual's interpretation of the term alloy steel. It may be useful for us to consider what is meant by that description; likewise, indeed, what is meant when we use the term steel, without qualifications.

Definitions of "Steel" and "Alloy"

12. Bradley Stoughton, in his *Metallurgy of Iron and Steel,* offers a definition for steel which is probably as satisfactory as any, when he describes it thus: "Iron which is malleable at least in some one range of temperature, and in addition is either (a) cast into an initially malleable mass, or (b) is capable of hardening greatly by sudden cooling, or (c) is both so cast and so capable of hardening."

13. Professor Stoughton truthfully states further: "The definition of steel is in a shockingly bad condition, and has been brought to it by a series of events which show the carelessness of the buying public and the greed of men who will appropriate the name for their product that will bring them the best price without regard to whether the name really fits or not."

14. It would seem that the careful consideration and general acceptance of this definition might terminate some controversies in respect to properly applicable terms to give certain ferrous metals that are noticeably of the high alloy variety.

15. The pocket encyclopedia called *Iron and Steel,* written by H. P. Tiemann, defines an alloy as "a union, possessing metallic properties, of two or more metallic elements, or of metallic elements and metalloids, which are miscible with each other, at least to a certain extent, when molten to form a homogeneous liquid, and do not separate into distinct layers when solid."

16. Webster's *International Dictionary* describes an alloy as follows: "A substance composed of two or more metals intimately united, usually by fusing the components together; also the state of union of the components; as brass is an alloy of copper and zinc."

All Commercial Ferrous Products Are Alloys

17. All industrialists realize that every commercial ferrous product is an alloy. One might say that it was incorrect in the first place to apply the word alloy as a distinguishing one, to a separate division of a material of such noticeably alloyed qualities as steel must be. But it would serve no good purpose, in emphasizing an inaccuracy impracticable to eleminate, due to continued universal acceptance, to advocate the employment of another term than alloy, used in connection with steel, for a comprehensive portion of the product which differs, in the combination of chemical elements composing it, from what is conceded to be average constitution of the metal as made for ordinary purposes, and possessing what may be called average properties.

18. Obviously, we must continue to use the term alloy steel as meaning a material that is distinguishable from the regular grade of steel, in respect to its chemical components.

19. The term "carbon steel," which is, to most persons, synonomous with "common steel," has been employed for years to indicate physical properties in the metal which are chiefly the result of the percentage of contained carbon. It is impossible, of course, to draw the line definitely, in any such consideration. And it would be a waste of time to try to establish mathematical ratios to indicate accurately, for all the characteristic properties of the metal ordinarily required in industry (speaking particu-

larly of structural purposes), what portion of the result is attributable to the carbon content, what portion is due to the manganese content, and what part the silicon content plays.

20. It seems satisfactory, for identification purposes, to continue to call the simplest grade of steel used for castings, carbon steel. Here, current terminology leads to no confusion.

Proposed Steps in Formulating Designations

21. Perhaps the most logical step in an attempted suitable designation of the grade that includes 1.25 per cent manganese steel (which might or might not contain the customary percentage of silicon, and contains, usually, a relatively low or an intermediate percentage of carbon) might be to consider the proportions of the five elements customarily determined in steel, as usually found in the regular grade of the metal produced in the foundry.

22. Thoughtful consideration of the entire matter seems, to the writer, to lead to the following conclusions:

(a) There should be chemical limitations agreed to in the steel casting industry, prompting general acceptance in the industries served, for concisely defining that product of the steel foundry which, by virtue of its chemical constituents, belongs rightfully in that grade which is meant when we speak of the "garden variety" of steel for castings, and which has been used for the bulk of the steel foundry output since the industry began its career in America.

(b) There should be general agreement on a definition collectively applied to those varieties of foundry steel which are "slightly alloyed," and lie in the intermediate zone between steel of customary chemical composition and steel that has such chemical constituents as now to permit classification without possibility of confusion on the part of anyone.

(c) Useful purposes would be served by a general agreement differentiating steels for castings universally recognized as of the alloy grade, but which do not touch another borderline, yearly becoming more important commercially, beyond which we now ordinarily classify the metal as being of the high alloy grade, sometimes called steel and occasionally given the inclusive designation (whether justifiably or not) of ferrous metal.

Suggested Classifications

23. The writer is prompted to suggest for discussion the following lines of demarkation, based on what is *intentionally* included in the composition:

(*a*) *Steel castings to be considered as being of the regular carbon grade*—

(1) when the content of carbon is not less than 0.22 per cent, or

(2) when the content of carbon is not more than 0.35 per cent; and

(3) when the content of manganese is not less than 0.50 per cent, or

(4) when the content of manganese is not more than 0.90 per cent; and

(5) when the content of silicon is not less than 0.20 per cent, or

(6) when the content of silicon is not more than 0.70 per cent; and

(7) when the content of phosphorus is not more than 0.05 per cent; and

(8) when the content of sulphur is not more than 0.06 per cent; and

(9) when there is no other element other than those mentioned, in an appreciable proportion.

(*b*) *Steel castings to be considered as being of the special carbon grade*—

(1) when the contents of four elements and no additional ones other than carbon, as indicated in the foregoing schedule under (*a*), are found in the material; and

(2) when the proportion of carbon is less than 0.22 per cent; or

(3) when the proportion of carbon is more than 0.35 per cent but is low enough to give the metal the essential qualities of steel.

24. If the limitations just suggested should be acceptable, there would automatically be identified as belonging to an alloy grade, foundry steel intended to contain—

(1) less than 0.50 per cent of manganese; or

(2) more than 0.90 per cent of manganese; or

(3) less than 0.20 per cent of silicon; or

(4) more than 0.70 per cent of silicon; or

(5) more than 0.05 per cent of phosphorus; or

(6) more than 0.06 per cent of sulphur; or

(7) an appreciable proportion of any element other than the five enumerated.

25. It also is proposed that steel foundrymen consider classifying as a simple alloy steel, any steel intended to contain no more than the five ordinary elements, but carrying with respect to one or more of these elements other than carbon, a percentage either less than the limitation previously suggested or more than the one previously suggested, but not exceeding 3.00 per cent.

26. Carrying the idea still further, some benefit might accrue by considering material as a low alloy or a regular alloy steel, when it is intended to contain an appreciable proportion of some element other than the five ordinary elements, provided the proportion of nickel does not exceed 5.00 per cent; also provided the proportion of any element other than nickel does not exceed 3.00 per cent.

27. Continuing the suggested line of thought, there might then be classified as a high alloy steel, steel containing more than 5.00 per cent of nickel, or more than 3.00 per cent of any other element. In such case, austenitic manganese steel would be graded, of course, as a high alloy steel, whereas now many are apt to think more or less restrictively of the chromium and nickel combinations, in speaking of the high alloy materials.

28. A general agreement along the lines suggested (but not necessarily following the limitations that are proposed for consideration rather than for adoption) would establish five grades (two of them being of the carbon classification) whose names and chemical compositions, if wisely chosen and widely recognized, would serve useful purposes in some purchasing industries as well as in our own industry. The names of the grades presented herein for discussion, repeated now in summarizing, are (a) regular carbon, (b) special carbon, (c) simple alloy, (d) low alloy or regular alloy, and (e) high alloy.

29. It is quite probable that agreement will be easier to

bring about in respect to the number of grades or varieties than in respect to names to be assigned to them; also (and more particularly) in respect to all the chemical limits suggested. The author would emphasize the fact that he advocates agreement only regarding some logical grading method as regulated by some appropriate chemical composition plan. In other words, the specific suggestions tendered are meant to stimulate discussion, inasmuch as, by the nature of the case, such questions never will be settled by talking only in generalities.

30. In commerce a term is useful if, by virtue of its very nature or by the result of adequate publicity, it becomes self-indicative to those interested in sale or in purchase. Selections of terms and limitations to apply to material described by the terms become matters of good judgment, to be exercised by those most conversant with the commodity under consideration.

31. Probably no steel foundryman would claim to have sufficient wisdom and experience to provide a terminology applying with the nicest precision to every phase of this matter. However that may be, the author makes no such pretensions.

32. It is hoped that this discussion of a topic which, so far as the writer knows, has not heretofore been advanced as one for discussion in any technical society, may prompt more appropriate suggestions than those contained in this paper; and that the outcome may be generally accepted definitions for all grades of steel for castings, each grade having its logical chemical boundaries.

DISCUSSION

WRITTEN DISCUSSION

A. W. GREGG:[1] No one conversant with present conditions can deny that Major Bull's paper is both timely and important. There is decided need for some logical method of grading or classifying the present bewildering array of alloys and alloy steels. The increasing production of alloy steels and their great variety call for some method of classification such as Major Bull has suggested.

[1] Bonney-Floyd Co., Columbus, Ohio.

No doubt it will be far easier to obtain general agreement as to the necessity for classification than it will be to obtain agreement as to where the lines should be drawn. The writer has always believed that alloy steels should be given names at least somewhat descriptive of their chemical composition, rather than trade names which are more or less meaningless. Also, he feels that the percentage of alloy or alloys should be stated frankly.

For example, a steel containing one-half of one per cent nickel and the same amount of chromium has useful properties which make it valuable for many applications. This steel may be truly described as a nickel-chrome steel, but if so described without some modifying designation, the effect is misleading and a buyer who does not inquire closely as to chemical composition or physical properties may be paying for something which he fails to receive.

It seems to the writer that the term "alloy steel" should be used only when some alloying agent other than the five usually determined constituents is added to produce a definite result. In general, alloys such as chromium, nickel, molybdenum, etc., are added to produce increased strength or hardness, or greater ductility for a given strength, or greater strength for a given ductility, or to promote increased strength at elevated temperatures, etc. This list might be extended greatly, but the purpose of the addition or additions is to produce some improvement in properties which cannot be accomplished so successfully if only variations of the five usual constituents are employed.

Steel containing 1.25 per cent manganese has valuable properties, distinguishing it from regular carbon steel; also, it is of great commercial importance. The writer does not feel, however, that it deserves inclusion in the class of alloy steels but would rather include it in the special carbon class.

Major Bull objects to the name "pearlitic manganese steel," but this name seems particularly appropriate and descriptive. Incidentally, the writer has heard this steel described as "high-manganese steel," in a shop which also was producing 12 per cent manganese steel and which they called "regular manganese steel."

Referring to Major Bull's suggested classification, upon which he has invited discussion, the writer believes there will be discussion only of minor details in arriving at agreement on the limits for regular carbon steel, or Class A.

As suggested above, Class B, or special carbon steel, would include steels containing the usual five constituents in percentages outside of those in Class A, but with an upper limit (perhaps 3 per cent), as suggested by Major Bull. This upper limit would exclude austenitic manganese steel.

Class C, or low alloy steel, could well be limited to the usual pearlitic or sorbitic alloys produced by additions to carbon steel of nickel, chromium, molybdenum, etc., with upper limits as suggested by Major Bull.

Class D, or high alloy steel, then would include the steels and alloys containing higher percentages of alloying material than those in Class C. Austenitic manganese steel could be included in Class D or be given a separate classification.

J. J. KANTER:[2] The idea of classifying various kinds of steel by using chemical analysis as a basis seems somewhat limited in what it can accomplish. Any classification on such a basis must necessarily be of an arbitrary character. It is, of course, a very convenient means, and has been widely used.

One of the most widely used systems of classification upon analysis is the S. A. E. number. This probably is as good a system of chemical classification of steels as has been advanced.

Major Bull, being primarily interested in classifying casting steels, establishes as "regular carbon grade" the following analysis, to which there probably is not much exception, unless, possibly, the carbon range is somewhat narrow:

Carbon	0.22 to 0.35%
Manganese	0.50 to 0.90%
Silicon	0.20 to 0.70%
Phosphorus	0.05%
Sulphur	0.06%

The great difficulty with chemical classification arises when we try to define alloy steel. Steel necessarily is an alloy under all circumstances, and when it is designated specifically as alloy steel, we mean that it is alloyed above the nominal ingredients of good carbon steel.

Alloy steel, as defined in the book "The Making, Shaping and Treating of Steel," by the Carnegie Steel Co., is: "Steels which, in addition to carbon content, contain another element or other elements in sufficient amounts to modify the properties to a marked degree over the carbon steels." In this book alloy steels are classified into four divisions, as follows:

(1) Simple alloy or ternary steels.
(2) Steels containing one alloying element besides the carbon.
(3) Quarternary steels—those containing two alloying elements.
(4) Complex steels—those containing three or more additional elements.

This scheme, however, does not attempt to fix definite limits establishing high and low alloys, and scarcely covers the scope of which the author of this paper speaks.

The terms "low alloy" and "high alloy," it is true, are being very loosely applied, to convey some idea of the aggregate percentages of alloying elements contained in steel. To some, these terms may merely imply something about concentration; to others, they are indicative of expense. Undoubtedly, also, these terms are sometimes taken to denote quality.

Major Bull would fix percentage limits as criteria of simple alloy, low alloy and high alloy steel. He suggests 3 per cent in general as the concentration of an additional element which places a steel in a high alloy class. While 3 per cent of one element may be enough to confer upon steel unique physical properties, 3 per cent does not necessarily produce a marked change in all cases.

[2] Testing Engineer, Crane Company, Chicago.

Again, we must consider the number of elements added as well as their aggregate percentage. Some of the elements used in steel are atomically light compared with iron—for example, silicon and aluminum. The atomic weights of these two elements are approximately one-half that of iron; that is to say, if either of these elements is alloyed with iron in the concentration of 1 per cent, about twice as many of their atoms are being added to the iron as iron atoms are displaced. Tungsten and molybdenum, on the other hand, are heavy compared with iron, and in alloying tungsten with steel, nearly seven times the percentage by weight is required to displace a given number of iron atoms as is required of aluminum.

From this consideration one would expect that the addition of 3 per cent of aluminum to steel would produce a relatively greater effect upon properties than would the same percentage of tungsten, and this we know to be true. For instance, the addition of 1 per cent of aluminum is enough to give the unique property of nitride hardening. It is well known that to attain pronounced effects from the presence of tungsten, concentrations of the order of 15 to 18 per cent are added.

Molybdenum, which has about half the weight of tungsten, produces specific effects at much smaller concentrations.

Since, after all, alloy steels are used for the specific properties they possess, it is necessary to classify the various chemical compositions according to the effects with which each one can be associated. One of the essential qualities of even the simplest alloy steels is its response to heat treatment, a behavior markedly different from that of carbon steel.

Superior physical properties of low alloy steels are theoretically attributable to the changes which alloying elements effect upon the critical transformations. Small percentages of alloy hardly can be blamed for converting iron into a solid solution with materially different properties. The carbon, as in plain steel, plays the principal role.

This idea, it seems, would be a good basis for defining low alloy steel. Such a definition for low alloy steel might be stated as follows:

> Steel in which the presence of dissolved elements other than carbon alter to a marked degree the iron-carbon equilibrium but do not suppress the austenite-ferrite transformation.

By iron-carbon equilibrium is meant not only the critical temperature relationship but also the rate of austenite-ferrite change. When this change actually becomes sluggish, it is often considered to be depressed. This definition of low alloy steel includes all of the comparatively low-priced alloy steels, even manganese steels, silicon steels, etc., because these steels are all uniquely distinguished from carbon steels in their heat treatment responses and resulting physical properties.

If we use the mechanics of transformation as a criterion, a definition for high alloy steel very logically follows. Most of the steels which are designated as high alloys are either unresponsive to heat treatment or very abnormal in this regard.

High alloy steel, therefore, might be defined as steel in which the

presence of dissolved elements other than carbon suppress a well-defined austenite-ferrite transformation.

Under this definition comes 18-8 metal, high-manganese steel, stainless steels containing more than 15 per cent chrome, high-speed steels and numerous others. Many of the steels which usually are considered on the borderline between low and high alloys would not be included under either this definition or the one for low alloy. Examples of these are the chrome steels in the range of 5 to 13 per cent chrome. Such materials as these could be designated, perhaps, as intermediate alloy steels.

The terms "very slightly," "low" and "high" alloyed steels undoubtedly convey quite concise meanings to the metallurgist. This is because the metallurgist thinks of steel in terms of numerous qualities and properties and other than mere chemical analysis.

From Major Bull's point of view, however, it is appreciated that the metallurgist's knowledge of steel does not suffice at all to guide the purchasers of steel castings in general. In general, the user of castings thinks of steel largely in terms of chemical composition, and for this reason it is certainly highly desirable that the metallurgical reasons for which a particular alloy is designated as "common," "low" or "high," be correlated in some way with chemical composition.

In order best to accomplish this end, it is highly desirable that a metallurgically scientific basis for classifying steels be adopted.

BRADLEY STOUGHTON:[3] Major Bull has put his finger on a very great need when he has pointed out the desirability of clarifying definitions and understandings of steels, alloy steels, etc. I fully agree with him as to the designation "medium manganese steel" to include the very large tonnage of steel—which I understand is in the neighborhood of 250,000 tons per year at present—containing between 1.50 and 2.0 per cent manganese.

Major Bull has attempted to classify steel castings, but it seems to me that to differentiate between castings and other types of industrial steel from the standpoint of definitions will lead us into greater confusion than exists at present, as was pointed out so well by Major Bull himself.

As an example of this, he classifies steel castings of "regular carbon grade" when they contain not less than 0.50 manganese, and 0.20 silicon, etc., and when the maximum amount is manganese 0.90 and silicon 0.70. This is certain to produce considerable confusion in the minds of those who are accustomed to forged electric steel, which will contain less manganese than this, or rail steels containing more manganese than Major Bull's maximum, or structural steels with lower silicon, etc.

[3] Professor of Metallurgy, Lehigh University, Bethlehem, Pa.

Similar confusion almost certainly would arise if one were to differentiate between castings and forged products on the basis of the carbon in his paragraph 23 (*b*).

Major Bull's suggestions are very important and valuable, and I hope that something can be done to follow them up. It is hoped that a committee may be appointed to suggest definitions. This is being attempted in the Committee on Definitions of Heat Treating Terms, formed by the A. S. S. T., S. A. E. and A. S. T. M.

ORAL DISCUSSION

R. A. BULL: In conversations I have had with friends in the business, it has been pointed out that nomenclature as applied to steel foundry practice merits more attention than it has received. Mr. Batty, among others, has expressed that opinion, in which I share; and I think consideration of that idea, perhaps unconsciously, prompted me to write this paper.

Occasionally I have been in contact with purchasers who have been perplexed because of the different ideas held by foundrymen as to what constitutes an alloy steel casting. There have been some steel foundrymen within my knowledge who, being very familiar with the manufacture of chrome-nickel steel, for example, have prompted some purchasers to believe that steel containing 1.25 per cent manganese or thereabouts is not properly classified as alloy steel. Of course, we in the foundry understand the distinction between kinds of casting steel, but often the purchaser does not, and gets considerably confused.

CHAIRMAN JOHN HOWE HALL:[4] Any classification is subject to an enormous amount of modification, and we hardly have time here to talk about the details of the proposed classification.

I think that, if any definition of alloy steel is to apply in the foundry, it has to be lined up, in the first place, not only with the steel casting industry but with the entire steel industry. We cannot get up definitions for alloy steel castings which do not agree with similar definitions for cold rolled and forged steels. Such a task is enormous; it will take a number of years to accomplish it.

From my experience in seeing the work that has been done in trying to get definitions of steel, I wonder whether we will not all be buried by the time a set of definitions is worked out. However, it would be a fine thing if a start could be made.

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[4] Technical Assistant to President, Taylor-Wharton Iron & Steel Co., High Bridge, N. J.

H. H. BLOSJO:[5] It has been my experience that cast steels having identical composition with rolled steels and forged steels do not have the same properties. Will Major Bull state his opinion as to this?

R. A. BULL: I believe it has been demonstrated that steel of a given composition that is rolled or forged, as compared with steel that is cast, shows less resistance to abrasion, to erosion, and to "creep" under high temperatures, and shows more stiffness in proportion to what one might call its elastic limit. I believe that Mr. Kanter of Crane Company has found in his laboratory that cast steel offers better resistance to creep under high temperature conditions than any kind of wrought steel, of the same composition.

The explanation of this seems to lie in the larger crystalline structure of the casting as compared with the forging or piece of rolled steel. Whether there are other differences in behavior I am not prepared to say, but I believe these facts have been established rather clearly.

J. J. KANTER: Major Bull has correctly indicated the results obtained in the Crane Company's laboratory.

H. H. BLOSJO: What I was mainly referring to was the ductility, elongation and reduction in area.

R. A. BULL: I do not think there is any doubt but that steel that is properly forged or rolled, of a given composition, has a higher ductility than cast steel.

H. H. BLOSJO: The relation is not necessarily the same for two different steels, is it? That is, taking in the S. A. E. specifications, the 3100 series and the straight carbon, is the relation between the ductility in the rolled, cast and forged steels necessarily the same?

R. A. BULL: No, it is not.

H. H. BLOSJO: I asked this question because, in the S. A. E. specification, with which I believe we all are acquainted, we have numbers designating the various types of steels, and also the various percentages of elements. I believe there probably is no better way of designating cast steels than by a designation similar to the S. A. E. specifications. That could be worked out very well, it seems to me, for cast steel in the same way as for rolled and forged steels, and I would like to hear further discussion on this.

W. C. HAMILTON:[6] My opinion in this matter of nomenclature is very closely connected with another problem of trying to prepare certain specifications for alloy steel castings. This problem has proven very difficult, mainly because we are going through processes of development at the present time.

I do not believe the majority of the manufacturers are in a position today to advocate specifications they would like to have applied to alloy steel castings. Until this development work has been carried further, I

[5] Metallurgist, Minneapolis Electric Steel Castings Co., Minneapolis.
[6] Research Director, American Steel Foundries, Chicago.

doubt whether we can get up satisfactory specifications. Probably the same thing applies to nomenclature.

It is a very important problem. There is considerable confusion existing now in connection with both specifications and the names for different alloy steels, and the subject should be given continued attention. I hope that in the near future the specifications and the names for alloy steels can be applied consistently.

CHAIRMAN JOHN HOWE HALL: A rather active sub-committee on specifications for alloy steel castings is now at work under the A. F. A. Committee on Specifications for Steel Castings. The thought in my mind, after reading this paper, was that this may be an opportune time for the A. F. A. to appoint a committee which would start the job of trying to develop nomenclature for alloy steels and alloy steel castings.

F. A. MELMOTH:[7] Major Bull certainly is quite right when he says there is a good deal of chaos at the present time in the nomenclature used for classes of steel. Also, I think that probably the Chairman's remarks that we will all be dead before it is really settled, are equally correct.

In the first place, I believe that common usage, which has been permitted to grow around this subject, will delay any proper settlement for a very long time. The main significance, I take it, of regularizing these things would be to enable purchasers to state exactly what they want. It has been our experience that very often the purchaser does not know what he wants.

Personally, I think that the settlement of these ranges, if we want to call them that, is a question for a select committee which would take the present knowledge on the subject, sift it, and try to evolve classifications which would meet both buyers' requirements and foundry conditions.

When first I read Major Bull's paper, I thought this would not be so difficult. Finally, however, I tried to classify the steels and found it was extremely difficult.

First of all, I do not believe that we could justify calling a steel an alloy steel merely because it has less than 0.22 per cent carbon. I think Major Bull put that up in order to be criticized, as I believe that he himself will admit that he would have great difficulty in selling to any one of his customers a steel, merely containing less than 0.22 per cent carbon, as an alloy steel. There common usage would beat him.

Consequently, I wonder if it is not possible to break these down into seven or eight families and then leave the proposed committee with the accumulated knowledge of the industry, to bring them into line and state definitely what they shall cover. Rough classifications that occur to me are:

No. 1 is dead soft, and I would call it that. It is low in carbon, and in almost every case low in manganese. The particular specifications force upon us low manganese as well as low carbon.

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[7] Assistant Manager, Detroit Steel Casting Co., Detroit.

No. 2 I would call straight carbon steels. It could be a family which covers steels of various carbon contents.

No. 3 and No. 4 could be more or less grouped together, as high-manganese or high-silicon carbon steels. They are essentially carbon steels. They contain a normal steel element to a larger extent than usual.

No. 5 could be termed the regular alloy steels. They are fairly well accepted in the other branches of the trade as three types, namely, nickel-chrome, chrome-molybdenum and nickel-chrome-molybdenum, etc.

No. 6 could be called austenitic nickel-chrome. This steel may be a little difficult to deal with commercially, but it is the only one I can think of that will fit, that covers such alloys as the 18-8 alloys.

No. 7 could be called austenitic manganese. That is an alloy steel and has a perfect right to a distinctive designation.

No. 8 might be the stainless chrome steels, which will cover the stainless irons and stainless steels.

Obviously, it is only possible to propose these tentatively and let other people shoot at them and evolve something from them.

CHAIRMAN JOHN HOWE HALL: I would like to entertain a motion, if anyone feels it is desirable, that it be recommended to the proper board or committee of the A. F. A. that a committee be appointed to at least survey the possibilities of starting this nomenclature work.

GEO. BATTY:[8] I so move.

H. P. EVANS:[9] I second the motion.

CHAIRMAN JOHN HOWE HALL: The motion has been made and seconded. Is there any discussion? If not, all in favor will signify by saying aye; opposed, no.

(*The motion was carried unanimously.*)

WRITTEN REPLY BY AUTHOR

R. A. BULL: The author observes that Mr. Gregg favors the term "alloy steel" only when an element other than carbon, manganese, silicon, phosphorus and sulphur is intentionally introduced—with an exception covering austenitic manganese steel, which Mr. Gregg would classify either as a high alloy steel or as a separate product entirely.

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[8] Technical Director, Steel Castings Development Bureau, Philadelphia.
[9] Hammond, Ind.

Before Hadfield developed this steel, probably many persons believed that any combination of the five regular elements, which had the characteristics of steel, should be designated as being of the carbon grade. The author thinks possible future utilization of now-unemployed proportions of some of the five ordinary elements might lead to more confusion among consumers than now exists, and might necessitate additional exceptions to a degree making Mr. Gregg's proposed basis unsatisfactory.

The author thinks a commercial disadvantage to our industry might result from classifying medium manganese steel as a variety of carbon steel. In suggesting the term "special carbon steel" for this material, we know Mr. Gregg does not mean it has a special or unusual carbon content. Nevertheless, some consumers probably would so misconstrue the description.

Mr. Kanter's comments include references to metallurgical phenomena which, while significant to the metallurgist, mean little or nothing to the average buyer of steel castings. Mr. Kanter evidently appreciates this fact, which is one that complicates the classification problem.

It seems to the author that, if trained metallurgists and semi-technical persons may not be able to completely agree, terms favored by the latter class would be preferable to terms of very accurate metallurgical distinction, advocated by those qualified to make them. A classification basis readily interpreted by those not metallurgically educated might be the more useful one that could be adopted for general application. The great majority of users of steel castings are not highly trained metallurgists.

It would indeed be gratifying if classifications equally satisfactory to the non-technical purchaser and to the skilled metallurgist could be devised.

Professor Stoughton favors a distinctive designation for what he and the author prefer to call medium manganese steel, rather than pearlitic manganese steel.

Professor Stoughton believes it unsafe to distinguish between castings and other products, in classifying grades of steel. This opinion carries great weight because of the high standing of the metallurgist who voices it, but the author is not fully convinced at present that serious complications would inevitably follow from different bases for classification.

A. S. T. M. specifications A95-29 for carbon steel castings for valves, flanges and fittings for high-temperature service, require minimum contents of 0.50 per cent and 0.20 per cent, respectively, of manganese and silicon. These restrictions are reasonable for carbon steel castings but not for certain wrought products of carbon steel, the important difference in desirability being, of course, associated with hot working. The author believes further consideration of this point should be given.

Mr. Hall's comments regarding uniform classifications for castings and rolled products have been touched upon in references just made to Professor Stoughton's discussion.

Mr. Hall is pessimistic as to the time required to develop classifications. An important factor would be the tediousness with which an

effort to get agreement in several technical societies is generally accompanied. The situation would be much simpler if steel foundrymen, after carefully considering the question, should feel their interests would be served by classifications applicable only to the product of the steel foundry, and readily understandable by purchasing agents and semi-technical representatives of buyers of steel castings.

Mr. Blosjo favors numerical classifications, as employed for S. A. E. steels. It is not clear whether he advocates use by steel foundrymen of the present S. A. E. numbers, or whether he favors a different numerical designation. That general method of identification has in its favor the fact that it has been found suitable for wrought products. Apparently it discourages the use of proprietary or trade-marked names for varieties of steel being increasingly exploited.

Mr. Melmoth's specific, alternative suggestions are helpfully advanced. However, he apparently has confused the author's suggestion in respect to 0.22 per cent carbon, when he argues against this limit for establishing a dividing line between carbon and alloy steel. Mr. Melmoth is referred to paragraph 23 (*b*) of the author's paper, which proposes that steel castings be considered as being of the "special carbon grade" when the carbon is less than 0.22 per cent.

The author appreciates the interest manifested in his paper and is thankful for the constructive spirit obviously actuating every individual who participated in the discussion. The author hopes that work which may be done by such a committee as will presumably be created to study the matter, will clarify it to the benefit of both buyer and seller.

Effect of Excessive Atmospheric Moisture in Cupola Blast

By Neil A. Moore,* Muskegon, Mich.

Abstract

Experiences leading up to the installation of a refrigerating system for the control of moisture in the blast, and reasons for deciding to install this system, are cited. The idea is developed that oxygen, above a certain amount, will cause cast iron to chill when poured into light castings. The effect of excessive moisture in the cupola blast is discussed, and also its relation to the oxygen content of the iron. The problem of the fluidity of cast iron is touched upon, and an attempt is made to show that it is influenced by the oxygen content of the iron. The effect of moisture control on the losses due to hard castings, and upon the operation of the cupola, is stated.

1. About seven or eight years ago, automotive engineers began to decrease the cylinder diameter of automobile motors and to use narrower piston rings. Consequently, piston-ring foundries were called upon to produce much lighter castings than they had been accustomed to make. With the production of these lighter castings, the problem of hard iron became a serious one.

2. In the foundry of The Piston Ring Co., it was discovered that the light castings would be hard at times and, at other times, with apparently no change in the practice, they would be soft and machinable. This condition continued for two or three years and gradually there developed in the minds of the operators of the foundry the conviction that weather conditions, with respect to the moisture content of the atmosphere, constituted an important influencing factor so far as hard iron was concerned.

* Metallurgist, The Piston Ring Co.

Note: This paper was presented and discussed before one of the gray iron sessions at the 1931 convention of the American Foundrymen's Association.

3. Before this idea could be subjected to investigation, foundry operations were transferred to a new building. Here the cupola was operated for ten hours a day instead of for two or three hours in the afternoon. What with this change and the radical changes in the molding methods and other details, all thought of the effect of weather conditions was crowded out by other problems demanding solution.

4. As these problems incident to the changes in operation were met and solved, what was thought to be the effect of atmospheric moisture again began to be noticed. Of course, it had never ceased to influence the cupola operation, but the numerous other difficulties had obscured its effect.

Table 1

EFFECT OF WEATHER CONDITIONS ON AMOUNT OF WATER BLOWN INTO CUPOLA

	On normal winter day.	On humid summer day.
Grains of moisture per cubic foot of air.....	2	10
Total gallons of water blown into cupola in 10 hours (using 3000 cu. ft. of air per minute).....	61.7	309.8

VARIATION IN WATER BLOWN INTO CUPOLA

5. Since it was true that clear, dry air did not trouble us, whereas damp, humid air seemed to, then it was plausible to expect that there must be an appreciable variation in the amount of water blown into the cupola on the two types of days. An examination of the government weather reports for the district showed that such an appreciable variation did occur between a normal winter day and a humid day in the summer. Table No. 1 gives some idea of this variation.

6. From Table 1 it will be seen that 248.1 gallons of water were being introduced into the cupola on a humid summer day over and above that blown in on an average winter day. Here, then, was a very appreciable difference that could easily account for the variation in the iron from the cupola on the two types of days.

ALL OTHER VARIABLES CONTROLLED

7. However, before definitely considering that atmospheric moisture was the source of our hard iron trouble, we carefully eliminated every other possible contributing factor. The cupola operation was closely watched every heat. The making of the bottom, the lighting and the burning of the bed, the amount of coke for the bed, the method of charging the cupola—all were standardized and held uniform.

8. Pig iron was purchased from reliable sources and each car received was piled separately and analyzed before being used. All materials going into the cupola were carefully weighed and charged by conscientious, dependable men. In making up the pig iron charges, iron was used from at least four different cars for each charge. This was done to minimize the possible bad effect of any off-iron.

9. When we had trouble with hard castings, we would carefully check up on our cupola operators and see that they were not at fault. Then we would juggle the pig iron in the charge, taking irons from different cars than we had been using. Also, we would change to coke from a different car.

10. Sometimes, of course, one of these changes would remedy the trouble. But there were many days on which no change that we could make in our ordinary method of operation, or in our pig iron or coke, would help the situation. It was because of this condition that we felt justified in laying the blame on the moisture content of the atmosphere, since the trouble was always the worst on the damp, humid days of spring and summer.

11. During these days it was almost impossible to run the cupola so as to avoid making a percentage of hard castings, especially on the lighter patterns. It was found that certain steps could be taken to mitigate the trouble, but it could not be entirely eliminated on such days.

12. In 1904, James Gayley[1] had published the results of his experience with the control of moisture in the air used for a blast furnace, but he was interested primarily in the matter of coke saving. Although he stated that the furnaces ran more smoothly after the moisture of the blast was controlled, he made no state-

[1]James Gayley, "The Application of Dry-Air Blast to the Manufacture of Pig Iron." *Trans.*, Am. Inst. of Mining Engineers, Vol. 35, 1905.

ments as to the effect on the quality of the metal produced. Nor had earlier or subsequent investigators dealt with the effect of atmospheric moisture on the quality of the metal.

INSTALL REFRIGERATING SYSTEM FOR BLAST MOISTURE

13. During the summer of 1928, the late Dr. Richard Moldenke visited our company's foundry in the capacity of consultant, and he convinced the company officials that it would be advisable to install a refrigerating system with which to control the moisture in the blast. The system was put into operation the following May, and has been used for every heat taken off since that time. Fig. 1 shows a diagrammatic scheme for such a system.

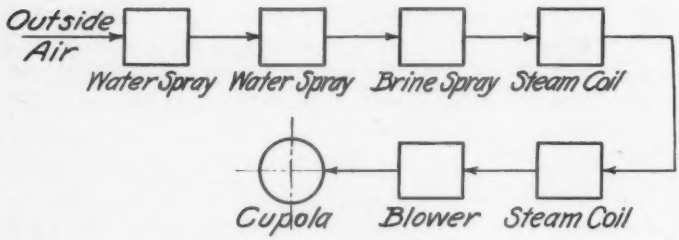

FIG. 1—FLOW DIAGRAM OF MOISTURE REMOVING SYSTEM.

14. In the foregoing paragraphs an effort has been made to recite the history of our experiences leading up to the installation of a means of controlling the moisture of the cupola blast. An attempt will be made now to discuss the way in which excess moisture in the cupola blast affects the hardness of piston-ring castings.

15. At the outset, it must be borne in mind that the castings which are affected are very light and that they have to be machined to very close limits. Many of these ring castings weigh less than one ounce, and it is because of this that ordinarily insignificant changes in the iron will produce, on the one hand, good machinable castings, and on the other hand, hard castings.

FORMER PRACTICE WITH PISTON-RING CASTINGS

16. A description of what used to be our experience on a day when the moisture content of the air was high will serve to illustrate the effect on our castings. Ladle iron would come down just before seven o'clock in the morning. Shortly after seven, the first molds coming around on the conveyor would be poured, and from then on the pouring would be continuous.

17. The castings would be free from chill until eight-thirty or shortly thereafter. Then we would find that on the lightest jobs the edges of the castings, at the back of the ring farthest from the gate, would begin to show a slight chill. The castings all were gated from the outside, at one point around the circumference. These castings with the chilled edges were, of course, scrap, as they could not be machined.

18. Our immediate remedy was to shut off the blast, bott up the tap hole and allow the iron in the crucible to lay there for three or four minutes. Then we would tap out and pour, and the castings would be all right. If the moisture content of the air was not excessively high, generally we would be able to get through the day with only a small loss due to hard iron, by repeating at frequent intervals the remedy cited above.

INCREASED COKE CHARGE TO OFFSET MOISTURE

19. However, if the moisture condition was bad, after we had shut down two or three times that remedy ceased to be effective. Then it was necessary to increase the amount of coke used on a charge. This naturally slowed up our melting and disarranged the balance between the metal from the cupola and the molds to be poured, and so was not to be resorted to until the other remedy failed. Besides that, it was not a sure cure for the trouble, so the desire to eliminate the cause was always present.

20. Iron which would normally make a machinable piston ring casting can be made to show a chill if poured into wet sand or if poured through an improper gate. No doubt there are other external conditions that will cause a ring casting to be hard. Temperature of the metal could be mentioned, but it has been our experience that, if the iron is anywhere near right, there can be comparatively wide variations in the pouring temperature without any subsequent effect on the hardness of the ring casting.

21. Therefore, if iron is poured into a ring mold and chilled castings result, when it is known that the external conditions are correct, then the trouble must lie in the iron itself. Something in it must hinder the normal dissociation of the cementite into ferrite and graphite, since it is cementite that is present in the chilled portions.

EFFECT OF OXYGEN ON NORMAL DISSOCIATION

22. What is the constituent in iron that retards this dissociation? In the opinion of the writer, it is oxygen in some form or other. The reasons for holding this belief follow.

23. Since we have been operating in the new foundry, we have always found it necessary to line our cupolas in such a way as to provide a large crucible or reservoir for molten iron. Our slag hole has always been eight inches above the tap hole, and this has allowed us to maintain a bath of molten iron approximately eight inches deep in the crucible of the cupola. And it has been necessary that we do maintain this bath.

24. In most every case where some operating difficulty has permitted the bath to get low, we have almost immediately encountered a stiffening up of the iron in the castings, and very often they have started to come hard. Naturally, when the iron has had a tendency to chill, it has been all the more necessary to keep the crucible full of iron. When the iron has been coming soft, a little more variation in the amount of iron in the crucible could be permitted without causing trouble.

REASONS FOR MAINTAINING FULL CRUCIBLE

25. There must be a reason why it is necessary to maintain a full crucible. The writer believes that by keeping the crucible full the molten iron has a chance to lay in intimate contact with the hot coke and profit by the deoxidizing action of this coke.

26. A low bath of iron has caused us trouble so many times, and the immediate increasing of the amount of metal in the bath has eliminated the trouble such a large percentage of the times, that there can be no doubt of the necessity of maintaining the full crucible. The explanation given above is the only logical one, in the opinion of the writer.

27. If this explanation is accepted, then it is a point in favor of the theory that, if oxygen is present in more than a certain quantity in cast iron to be used for piston rings, it will cause hard castings.

REMEDIES USED TO REDUCE OXIDATION

28. Consider now the two steps we formerly took to eliminate hard castings on days when the excessive moisture content of the atmosphere apparently was causing the trouble. First of all, we would bott up the tap hole and hold the bath of metal in the crucible with the blast turned off. Here then, was an opportunity for the molten metal to be deoxidized, since the melting zone was filled with incandescent coke and only a comparatively small amount of air. The gas in the cupola must have been largely CO, and this, along with the hot coke, would act as a powerful deoxidizer.

29. The second remedy was to increase the amount of coke on the charge. Had this been accompanied by an increase in the amount of blast, it would have been a different story; but it was not.

30. It was found that if we increased the blast when we increased the coke charge, we failed to get the results desired. So, when the coke charge was increased without a corresponding increase in the amount of blast, we naturally slowed up the melting and changed the balance between the coke and air.

31. The writer believes that this change in the ratio of coke to air, in a way that increased the amount of coke, brought about a condition in the cupola by which the proportion of CO gas was increased, and that this gas acted as a deoxidizing agent and thus served to eliminate the tendency of the iron to chill. Here again seems to be a point in favor of the theory that oxygen is responsible for the trouble in question.

32. One must continually bear in mind that the castings under discussion are very small, and that their hardness is affected by seemingly insignificant changes in the iron. This being true, it would be feasible to believe that they could be affected by a very slight increase in the oxygen content of the metal with which they are poured.

HOW EXCESS MOISTURE ACTS IN THE BLAST

33. If the writer's theory is correct, namely, that oxygen over a certain amount will cause cast iron to chill when poured into light-section castings, then the question arises as to how excess moisture in the atmosphere can bring about such an increase in the oxygen content, and consequently be held responsible for our hard ring castings.

First Explanation.

34. There seem to be two explanations of how excess moisture in the blast can act. First of all, it takes heat to raise the temperature of the water in the blast from the temperature of the incoming air to the temperature of the melting zone. This, of course, reduces the amount of heat available for the melting of the iron above each coke charge.

35. However, the big factor is the heat taken up by the dissociation of water into oxygen and hydrogen in the presence of incandescent coke. This reaction always occurs, and it takes away a really significant amount of heat which would otherwise be available for melting iron. With these two sources of heat loss, it is conceivable that the bed is gradually reduced until oxidized iron results.

36. This explanation would seem to be supported by the fact that formerly our trouble never appeared until we had run for an hour or two. On the other hand, had the bed been lowered there should have been a noticeable decrease in the temperature of the iron, and this never happened. Consequently, the writer is not inclined to favor this explanation, but has given it for what it may be worth.

Second Explanation.

37. The second explanation to be suggested is that when the water in the blast dissociates in the presence of incandescent coke into oxygen and hydrogen, the oxygen so formed is in a very reactive state and immediately combines with some element or elements in the iron and enormously increases the tendency of the iron to chill. This explanation seems to be the one best suited to each of the different experiences that we have had with chilled castings caused by excessive atmospheric moisture.

LACK OF LITERATURE ON THE SUBJECT

38. Turning now to the literature dealing with the effect of excessive atmospheric moisture on the hardness of cast iron made in the cupola, one finds that very little has been written on the subject. Quite a lot has been written concerning the effect of moisture on blast-furnace operation, but here the discussion has all centered about the matter of saving of coke and smoothness of operation of the furnace. The effect of furnace operation on the pig produced, and, in turn, the effect of that pig on the castings made from it in the cupola, has been investigated by only one writer.

39. Boegehold,[2] in his paper presented before the American Foundrymen's Association in 1929, described an excellent piece of work along this line. His researches showed that it was easily possible to run a blast furnace in such a way that the pig iron produced had a high content of oxygen. When this pig iron was charged into a cupola, the resulting cast iron had, among other characteristics, a very marked tendency to chill, and it was hard to machine.

40. Among the different furnace operating conditions which produced pig iron with high oxygen content, he found that excessive moisture in the blast was an important one. Pig iron produced under this condition resulted in cast iron with a marked tendency to chill, when it was remelted in a cupola. If, when this pig iron was melted in a cupola, the moisture in the cupola blast was high, then the tendency of the resulting cast iron to chill was greatly increased.

AUTHOR'S FINDINGS SUBSTANTIATED

41. Our conclusions check with those of Boegehold's remarkably well. Surely, if it is possible to make pig iron with an oxygen content high enough to affect the castings made from that pig, it is just as easy to melt iron in a cupola under conditions that will bring about a high oxygen content and consequently hard castings, especially when the iron is used for light work.

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[2] A. L. Boegehold, *Quality of Pig Iron and Castings as Affected by Blast Furnace Practice.* TRANS. Am. Foundrymens Assn. (1929), Vol. 37.

42. In discussing Boegehold's paper, J. E. Fletcher stated that his experience led him to believe that moisture in the blast could cause hard castings.

43. During the same discussion, R. M. Allen suggested that it was not water, as such, in the blast that caused the trouble, but rather the nascent or reactive oxygen and hydrogen coming from the dissociation of that water. This idea coincides with the writer's, as expressed in an earlier paragraph.

44. Chemical analysis never has disclosed any difference between the total carbon, sulphur, phosphorus, manganese or silicon in the hard castings and in the normal run of iron as we make it. True, there is a difference in the amounts of combined and graphitic carbon, but these tell that the castings are hard, and not why they are hard.

EXCESSIVE MOISTURE SUCCESSFULLY ELIMINATED

45. Regardless of whether or not the writer's theories as to the effect of excessive atmospheric moisture in the cupola blast on the hardness of piston-ring castings are correct as set forth in this paper, the elimination of that excessive moisture has been an outstanding success.

46. Our hard iron losses have dropped to an almost negligible percentage. Fully seventy-five per cent of our cupola operating difficulties have disappeared. Because of smoother and more accurate control, we have been able to make reductions in the amounts of limestone and fluorspar used and in the amount of coke between charges. These have more than offset the operating costs of the system, and as a result the better quality of iron produced has been all clear gain.

47. It is true that we still have occasional trouble with hard iron, but in every instance in which it has occurred since we have had moisture control, we have been able to trace the trouble to the way the cupola was being run, or to bad coke or off-pig iron. These causes of trouble have been comparatively simple to correct.

48. There are many problems still to be solved in our foundry, but the moisture control system, by eliminating one variable, has made it easier to distinguish these problems. The fluidity of our iron is an important consideration. We have discovered seem-

ingly strange facts about the fluidity of cast iron, and these facts do not check with the ordinary accepted ideas on the subject.

VIEWS ON FLUIDITY OF IRON

49. This question of fluidity would seem to be outside the scope of this paper, but the writer believes that fluidity is closely connected with the oxygen content of the metal. If this is the case, then it has a place here after all.

50. It is generally believed that oxidized iron lacks fluidity, or the ability to run castings. This may be true, provided the oxygen content is very high.

51. However, it has been the writer's experience that iron with an oxygen content high enough to cause chilled piston-ring castings is very fluid. On the other hand, the writer believes, based on his own experience, that if the oxygen content of cast iron is reduced below a certain point, the iron will become very sluggish and will not run even comparatively simple castings.

TESTS ON FLUIDITY

52. About six or seven years ago, while running an electric furnace in the company's foundry, it was found that the fluidity of the metal showed remarkable variation in a short period of time, under the following conditions: We were attempting to run continuously, and would start out in the morning with a cold charge of 3000 lbs. After this was up to temperature, we would start to pour. Approximately 500 lbs. of iron would be poured every fifteen minutes and, immediately after pouring, an equal amount of cold metal would be charged to keep up the bath. By ten or eleven o'clock in the morning, the furnace would be extremely hot. The bath of metal would be covered with a siliceous slag in which there was some crushed carbon electrode.

53. The iron would be fluid enough to run the ring castings without any trouble. However, if we shut both doors of the furnace and continued to apply current, inside of five minutes the iron would lose its fluidity to the extent that it would not run even one-quarter of a comparatively heavy ring. Obviously, it was not because the metal had cooled off.

54. If, after this loss of fluidity occurred, we opened the

charging door, threw in a shovelful of mill scale and rabbled it into the bath, we found that the fluidity immediately returned. Unfortunately, we never were able to judge accurately how much mill scale to add, and the result was that the fluidity returned after such treatment but the castings were white hard.

RELATION OF OXYGEN CONTENT AND FLUIDITY

55. This experience led the writer to feel that there was some relation between the oxygen content of cast iron and its fluidity, for it seemed that the fluidity was lost when the condition in the furnace was made highly reducing, and it returned when mill scale, or iron oxide, was added to the bath.

56. However, it was not until later, when connected with the cupola operations, that such a condition arose again and so made the evidence very impressive. The writer found, when the cupola metal was running to the soft side but still was fluid enough to run the castings, that the fluidity could readily be lost by botting up the tap hole and allowing the bath of metal in the crucible to stay there two or three minutes with the blast off.

57. It may be argued that the temperature of the metal dropped and that this would account for the loss of fluidity, but this was not true. The temperature drop always was too slight to have any effect.

58. Earlier in this paper it has been stated that when the iron was coming hard, the tap hole would be botted up and the bath of metal in the crucible allowed to lay there for two or three minutes with the blast off. This treatment would make the iron soft, evidently by reducing its oxygen content.

59. Why is it not plausible to suppose that if the iron is soft, due to low oxygen content, and then the metal is held in the crucible as described above, the oxygen content again is reduced, this time to a point where the fluidity of the metal is affected? This would seem to check the experience with the electric furnace.

60. It is the writer's understanding that the Bureau of Standards has just completed some work on electric-furnace cast steel, and that their experience with fluidity checks that described above. At the time this is being written, the findings of the Bureau have not been published.

NEED TESTS FOR COKE AND PIG IRON QUALITY

61. The question of proper tests to determine the desired qualities of coke and pig iron is another problem that faces us. Here again we feel that the moisture control system will help by cutting out one variable in the cupola operation, and so making it easier to observe the results with different cokes and irons.

62. No doubt there are a number of different systems, all of which will serve to remove excess moisture from air and also control the moisture content. Any company interested would have to work out the particular system best fitted to their needs.

63. At the present time, in Scotland, a blast furnace is being operated with air which has been passed through silica gel.[3] By this means the moisture can be controlled at a very low cost, according to the operators of the furnace. Whether or not this method can be considered beyond the experimental stage is an open question.

MOISTURE CONTROL SYSTEM DESCRIBED

64. For those who may be interested, a short description of our system is included in this paper. Fig. 1 shows a flow diagram of this system. In the summertime, air is taken from the outside. In the winter, outside air is mixed with air from inside the building, the object being to help control the final air temperature. The two stages of water spray are used whenever they can serve to lower the air temperature. This is mostly in summer, when ordinary water temperature is lower than that of the air.

65. The brine spray, of course, accomplishes the final cooling. Air coming from this spray is kept at a constant temperature. Calcium chloride is used in the brine system and ammonia coils serve to cool the brine.

66. After the air comes from the brine spray, it is passed over steam coils and heated to room temperature. Since the refrigerating plant is in the basement and the cupola blower on the second floor, this heating eliminates condensation of moisture on the pipes.

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[3] E. H. Lewis, "The Use of Silica Gel as a Medium for Drying Blast," *Journal*, Iron & Steel Inst., No. 2, 1927; also, "Twenty Months' Results of Dry-Blast Operation," *Journal*, Iron & Steel Inst., vol. 119, No. 1, 1929.

67. The second steam coil is just ahead of the blower, and here the air is heated to about 150 degrees. This is accomplished with exhaust steam and helps to keep the tuyeres clean and also slightly increases the cupola efficiency. From there on, the air travels through a positive blower and into the cupola.

68. We maintain a temperature of 35 degs. Fahr. as the air leaves the brine spray. Since the air is saturated, this means that it contains just a trifle over two grains of water per cubic foot.

SUMMARY

69. To sum up, the writer believes that excessive atmospheric moisture in the blast for the cupola will increase the tendency of cast iron to chill, and consequently will cause hard castings, provided they are as light as piston rings.

70. Also, it is believed that the excessive moisture increases the oxygen content of the iron and that it is this increase in oxygen content that is responsible for the retardation of the breaking down of cementite into ferrite and graphite, and the consequent hardness of the castings due to the high content of cementite.

DISCUSSION

WRITTEN DISCUSSION

A. L. BOEGEHOLD:[1] Mr. Moore is to be congratulated on the clear and concise way in which he has explained the circumstances surrounding the occurrence of hard iron, and the methods used to eliminate it. I have been convinced for a long time that excessive moisture in the blast increases the tendency of the iron to chill, and now Mr. Moore's paper strengthens this conviction.

After all, daily production experience, pointing to reduction in the amount of hard iron by drying the blast, is the best kind of proof because it is repeated every day. Every foundryman knows that when the bed burns low in a cupola and the iron is not melted until it gets down close to the tuyeres, the result is badly oxidized iron which is excessively hard. The oxidation is excessive because the solid iron remains so long in the oxidizing atmosphere.

[1] Metallurgist, General Motors Research Laboratory, Detroit.

When the iron melts 30 to 36 inches above the tuyeres, it falls through the high oxygen zone in front of the tuyeres fast enough so that not much oxidation occurs. But, on increasing the amount of water vapor in this zone, what happens? This water vapor not only dissociates in contact with incandescent coke, but it also contacts with each drop of iron falling through this zone, resulting in the formation of nascent oxygen right in contact with the iron so that there is no chance for it to combine with anything else but the iron.

If there is anyone who does not appreciate the difference between the oxidizing effect of molecular oxygen as it occurs in the air blast, and nascent oxygen formed upon the dissociation of water, let him take two pieces of steel and heat them to about 2000 degs. Fahr., in a neutral atmosphere to prevent formation of scale, and then cool one in a blast of dry air and the other in a jet of steam or atomized water, and observe the difference in the amount of scale on the surface. The steam or water-vapor cooled specimen will be a great deal more scaled than the one cooled in dry air.

Referring to Table 1 of Mr. Moore's paper, it will be noted that there are about 310 gallons of water blown into the cupola in 10 hours when there are 10 grains of water per cu. ft. of air. With the amount of air used, there will be, presumably, about 60 tons of iron melted in 10 hours, so that for every 100 lbs. of iron melted there is, roughly, one quart of water blown into the cupola. The amount of steam derived from one quart of water should certainly have an appreciable oxidizing effect on 100 lbs. of finely divided molten iron.

ROY M. ALLEN:[2] Mr. Moore has forged one more link in the chain of evidence as to the part played by atmospheric moisture in cupola operation. Practical demonstration such as he has given, of its influence on the nature of iron, is badly needed. He deserves thanks for its presentation.

Some metallurgists hesitate to accept the theory that oxygen plays any part in the final characteristics of gray iron, but the mass of evidence that is gradually accumulating is such that it must be reckoned with. Its effect on many nonferrous metals and in steel, the latter so ably discussed by Grossman in his paper before the 1930 convention of the American Society for Steel Treating, would make it seem strange if it did not play some part in the nature of cast iron as well.

In heavy gray iron castings the effect is masked by a preponderance of other elements and factors; but when we are working with light castings where strength is also essential, or with chilled iron where the margins between the required softness of the gray portion and the desired hardness of the chill are so small, there are opportunities to

[2] Consulting Metallurgist, Bloomfield, N. J.

observe and appreciate its effect. From my own work with this latter class of casting, I have long been convinced that it does play a considerable part here also. As there are so many variables in cupola operation, the recognition and elimination of this as one of them, are steps toward final greater uniformity of product.

While I believe we are safe in assuming that it is the result of the breaking down of the water into hydrogen and oxygen, and the nascent condition of the latter, that is responsible for the tendency to produce hard iron, we are not at present justified in going much farther, in the light of such evidence as is available. The possibility of the effect being caused by the loss of heat in raising the temperature of the water, or in its decomposition, need not be considered, because a following through of all the heat transfers and chemical reactions involved will show that such cannot be the case.

Numerous theories might be suggested to explain what happens and to serve as a basis in working out the answer, among which the following appear to be the more logical:

1—At temperatures involved in cupola operation, the affinity of oxygen for silicon is greater than for other elements present. Oxidation of even a slight amount of this element would mean lowering it a few points, and as we are considering conditions within very narrow limits, any reduction of silicon might be at least a factor in the resulting hardness.

2—Manganese might also be oxidized and therefore lowered a few points. When this element is materially under the silicon content, an increase in it tends to give further softening; conversely, a reduction tends to harden. If the manganese is around the value required to offset the action of sulphur—that is, about three and one-half times the sulphur content—the hardening effect is very marked, possibly because all the sulphur is not converted to manganese sulphide; and, as a single point of sulphur is equal to at least 15 points of silicon, it is just as though this latter element is lowered by that amount for every point of uncombined sulphur.

3—A few points of carbon may also be oxidized, thus causing a slight lowering of the total carbon. Within the ranges we are interested in, there is practically a direct relation between the total carbon and the silicon content, insofar as graphitization is concerned, so that as the former is lowered one point, the latter must be raised one point to give equivalent results. This might help explain why the trouble could be corrected by allowing the iron to lie in the cupola, which should logically result in a few points pick-up of carbon. If the combined effect of all three of these possibilities were present, it can be seen that without an apparent difference in the composition of the resulting iron, there still might be sufficient cooperating differences to bring about a hardening.

There is another possible explanation, which seems to have been entirely overlooked, even by Grossman in his classical paper. While it seems perfectly logical and a very simple explanation of the cause of the hardening, we have at present no positive basis for accepting it as the true one.

This is the possible existence of some carbonyl of iron which may

be extremely stable and difficult to break down, even in the presence of abundant silicon or other graphitizing elements. It is easily possible that the presence of an atom of oxygen in an otherwise plain carbide might completely change its resistance to silicon, and that it might in other respects behave as a carbide so that we would reckon it as such, even in analysis.

In the absence of definite data on the compositions of Mr. Moore's irons, and information as to the limiting values representing the difference between a satisfactory and unsatisfactory product, it is impossible to come to definite conclusions from his paper. It is suggested that the subject is worthy of further study on Mr. Moore's part, as the nature of the product his firm is interested in is such as to make him a logical man to carry on the investigation.

As to the suggestion in his paper that oxygen gives fluidity, the instances cited cannot be considered conclusive as they are susceptible to other explanations.

H. E. CLARKE:[2] Mr. Moore's theory that the addition of iron oxide to molten iron increased its fluidity, because oxygen was added to iron, may be correct; but it is certainly not *necessarily* correct, because there is no way of knowing whether oxygen was added to the iron or removed from it. If oxygen in iron is carried in compounds like silicates, then it is entirely possible that the iron oxide combined with some such compounds and thus actually removed oxygen from the iron.

We can recall many cases of materials containing oxygen being added to other materials which also contain oxygen with the result that the latter materials are precipitated out of solution. Thus oxygen is removed from solution by the addition of oxygen. It seems, therefore, as though it might be possible to remove objectionable impurities from iron by additions of iron oxide or other oxides.

ORAL DISCUSSION

NEIL A. MOORE: I want to bring out, in connection with Mr. Boegehold's discussion, that we are not melting 60 tons of iron in 10 hours; we are melting approximately 30 tons. Thus, the result is two quarts of water to 100 lbs. of iron, rather than one quart.

In Mr. Allen's discussion regarding his first explanation of the possible

[2] Foundry Engineer, Sloss-Sheffield Steel & Iron Co., Birmingham, Ala.

effect of silicon, let me say that our experience has been this: The effect of silicon on the hardness of a piston ring casting is a secondary one. That may not seem logical, but we have found it to be true.

The size of the section has so much greater effect on the hardness of the casting than has any silicon content, that we have found we can vary the silicon in these castings from two to three per cent without variation in the hardness, by controlling the cupola operation. In other words, we can pour two per cent silicon iron into these castings off the bed of a cupola and get softer iron, under certain conditions, than we can with three per cent silicon under other conditions.

The reason why I did not give any analyses in my paper was because the subject matter that I was presenting was apparently so controversial that, had I mentioned chemical analyses, it would have been merely presenting another point which would have elicited discussion and probable controversy. In order to avoid this, I eliminated it from the paper, although we have made, of course, many chemical analyses.

R. F. HARRINGTON:[4] Mr. Allen brought out a point that I had intended touching upon, for I had intended asking Mr. Moore if an analysis of the iron that had been held in the crucible of the furnace for three or four minutes, and which did not produce chilled rings, showed any differences in the relation of the question of carbon.

NEIL A. MOORE: I have some reports of tests that we ran, not from the standpoint that Mr. Harrington mentions, but from the standpoint of proving my point in the matter of fluidity. However, I believe some data from these tests will clear up that subject in relation to hardness as well.

Of the two analyses, one was made at 11:32 in the morning, the other one at 11:39. We had shut down during that period; the blast was off for approximately five minutes. After the blast had been off two minutes, we opened up the tap hole and drew down the iron in the crucible, and after it had been drawn down for about three minutes we botted up, put on the blast and ran until 11:39, when we poured a second test bar. The iron was running very well when we shut down at 11:32. At 11:39 the iron was mis-running slightly.

The analysis for total carbon was 3.50 at 11:32, and 3.49 at 11:39. Silicon showed 2.72 at 11:32 and 2.71 at 11:39.

There appears to be, in our experience, no fundamental change in the analysis of total carbon or silicon to account for the differences in hardness that we get under the different conditions. In other words, we have not been able to demonstrate that allowing that iron to be in contact with the coke for three or four or five minutes has picked up any carbon.

ROBERT H. WATSON:[5] In our operation, while we had three blast furnaces we only had sufficient dry blast for one furnace. We would change from day to day, putting the dry blast on No. 1, No. 2 or No. 3 furnace.

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[4] Metallurigst, Hunt-Spiller Mfg. Corp., Boston.
[5] Metallurgist, Semet-Solvay Co., Detroit.

We would add 25 per cent to the weight of the burden and bring the iron down, using the dry blast, without any change in the silicon. We were trying to get 1.60 to 1.75 silicon for the bessemer converters.

I also found this to be true in securing drillings for test—the test piece from the dry blast always was much harder to break in half, but much easier to drill.

Also, we found, in taking this iron later and operating in open-hearth furnace on slightly higher phosphorus, that under similar conditions iron made under the dry blast worked faster in the furnaces.

In going to larger plants where we did not have the dry blast, I used a sling psychrometer and secured the amount of moisture in the air four or five times a day. After using this instrument, I doctored the coke according to the amount of moisture that happened to be in the air.

Referring to cupola practice, in those earlier days a man who ran a blast furnace had to run the cold iron cupolas to melt for the bessemer blowers. In following that cupola practice I have also taken a great many tests with the sling psychrometer and have found that the moisture in the air certainly had a great deal to do with the temperature of the iron.

I also found, with iron made under conditions where we had a very low humidity, along in winter as up at Sault Ste. Marie and in Ontario, that there certainly is quite a difference in machinability.

H. E. CLARKE: Mr. Moore brought out the point that when he left the iron in his cupola it became softer, and he attributed this to the fact that it lay in contact with the coke. I wonder if it is not possible that the softness was due to its lying in contact with the slag. I would like to know whether Mr. Moore has varied the slag in his cupola by using less limestone, more limestone, or sand or other materials in an attempt to eliminate defects in his castings.

In this connection, I think there is a possibility that this year's convention paper on a manganese silicate inclusion in cast iron, by F. J. Cook of England, has perhaps shown us a way to better castings without resorting to expensive means such as the electric furnace or dry blast. If cast iron contains manganese silicate, there is a possibility that it also contains other complex silicates.

If some such silicates were causing Mr. Moore's trouble, he could not reasonably expect to eliminate them by reducing them with coke, because manganese silicate is a salt similar to clay—which cannot be reduced—rather than a simple oxide which carbon will reduce. It looks as though the only way we can hope to remove silicates from iron is to cause the molten metal to come into contact with a slag of a composition which will combine with them.

This brings up the question: Is it not possible that cupola slags of varying compositions may be very useful as a means of purifying iron? Good fluid slags may be made in the cupola with varying amounts of such inexpensive materials as dolomite, clay, sand, soda ash, fluorspar, iron ore, mill scale and perhaps salt. So far as I know, no one has yet explored the possibility of making superior castings by use of various

mixtures of such materials. It seems not impossible that with certain slags in an ordinary cupola, cast iron can be made quite as good as electric iron or dry blast iron.

NEIL A. MOORE: I must confess at the outset that the idea expressed by Mr. Clarke has not occurred to us, and we have not done anything along that line. Our problem was the continuous operation of a small cupola, such as we have, as to produce a three-eighths inch stream of iron all day long. It has been necessary to put enough limestone into the charge to make this cupola slag continuously, from the rear, and still not to get too much. When we get too much, the slag is too fluid and cuts out our slag hole and gives us a great deal of trouble from an operating standpoint.

It is entirely possible, of course, that Mr. Clarke's explanation is correct. I cannot answer it.

J. T. MACKENZIE:[6] I would like to emphasize one point which has not been brought up, that Mr. Moore's iron is running right at the eutectic. In coming to this point, it makes quite a difference whether one comes from above or below. If one has the eutectic and comes down from a very slightly higher percentage of carbon, it will be found that the iron is very much softer than when coming up from it, and the difference often is too small to be shown by chemical analysis.

I take it that anyone present would assume five-hundredths of one per cent to be a fairly decent check on the chemical analysis for total carbon. If that is the case, it will be found that when the carbon is just above the eutectic, in freezing a little primary graphite will freeze out first, which accelerates the formation of graphite and produces a soft iron.

On the other hand, coming up from very slightly underneath the eutectic, there is no primary graphite formed, so that the cementite formation is favorable.

I do not mean by this to discredit the oxygen theory. I simply want to draw attention to the fact that the eutectic is a very delicate point, not even considering the oxygen.

CHAIRMAN J. D. STODDARD:[7] The point Mr. MacKenzie makes is an excellent one. Further, one point which should be emphasized is the reference to the possible accuracy of checked results of total carbon determination. Five-hundredths would be considered as a good check. Five-hundredths difference in total carbon may have the result and produce the effect that has been noted in Mr. Moore's paper. We do not know that that is true, but it may have that effect.

MEMBER: Was any effort made to solve this hardness problem through the high-powered microscope? Also, were there any effects of heat treating? Could this hardness be eliminated through an annealing practice?

NEIL A. MOORE: In answer to the first question just asked, we have

[6] Metallurgist, American Cast Iron Pipe Co., Birmingham, Ala.
[7] Vice-President and Treasurer, Detroit Testing Laboratory, Detroit.

not gone to use of the microscope for a possible solution of the problem.

In answer to the second question, we are making 300,000 castings a day and they have to be essentially flat when they go to the machine shop. The problem of annealing becomes one to which one would not resort until everything else has failed.

I have tried annealing piston rings and there is a very decided effect on the structure in annealing up to 1150 degs. Fahr. A softening is obtained, all right, but the softening is due to a breaking up of the structure and the result is not the same as is obtained by producing a soft casting at the start.

T. F. KILEY:[8] I am inclined to agree with Mr. Moore's theory of oxidation on this trouble with hard spots. I know that at one time we made piston rings and we experienced more or less of the same trouble on a piston ring of one-eighth inch section. It had a tendency to chill at the far point from the gate.

We found that an addition of powdered ferrosilicon helped out considerably, indicating possibly that the iron was somewhat oxidized and that the ferrosilicon helped to deoxidize it.

I will say, in connection with this matter, that when we made the ferrosilicon addition we had more or less trouble with small gas holes showing up in the piston ring on removal of the skin of the castings in machining. Thus, this method did not work out so well.

NEIL A. MOORE: Possibly there are many ways by which this trouble can be overcome, but it should be borne in mind that we are running a production shop and like to do things that cause us the least trouble and which we can control uniformly. Regardless of the expense involved in the operation of a dry blast, the saving in operating costs probably would be far greater than trying to doctor each ladle of iron.

We have eight men pouring with 50-lb. hand ladles throughout the day, and it can be seen from this that it would be practically impossible to make ladle additions.

ROY M. ALLEN: In order to clear up one point, I would like to ask if Mr. Moore can tell us his average manganese and sulphur content?

NEIL A. MOORE: The average sulphur content is around 0.07 to 0.08 per cent. The average manganese runs from 0.60 to 0.65 per cent.

M. J. GREGORY:[9] We have had a number of fine papers on electric furnaces, very finely controlled. Now we have one on an "un-fine" control or poor control of the cupola. I wonder if Mr. Moore could give us a line on both electric and cupola. I believe he has had some experience with both on the same class of work.

NEIL A. MOORE: We operated an electric furnace experimentally some years ago—not so many years ago in point of time but many years ago in point of electric furnace experience. Consequently, it is only fair to say that while we did not find this electric furnace suitable to our operation, it might have been because of the lack of experience and

[8] Metallurgist, Brown & Sharpe Mfg. Co., Providence, R. I.
[9] Factory Manager, Caterpillar Tractor Co., Peoria, Ill.

the lack of knowledge which was available at that time. When we were operating the electric furnace I went to every place in the country where I knew they were melting cast iron electrically, and each one had a particular problem.

Of course, from our standpoint the power cost in the Muskegon district was so high—2.10c per kilowatt—that it practically prohibited the use of the electric furnace, regardless of results obtainable. Our melting cost at the spout was approximately three times the cost at the spout for cupola melting.

MEMBER: Were there any characteristics of the molten iron that were noticeable when this hardness condition existed? In other words, did the molten iron show any kind of frost on the top, or was there any special characteristic noticeable?

NEIL A. MOORE: It is rather unusual, I know, but in our shop, when we used to have variable conditions—conditions in which the iron was inclined to be hard—if we had to pour iron to make such castings as this, it was our common practice when the iron was too hot, to throw some loose scrap in the bottom of the ladle and actually cool the iron down 100 to 150 degrees before pouring the castings. Very often this helped to keep them soft.

In other words, it is entirely possible, although it does not seem logical, to pour iron so hot that a casting such as this can be chilled, whereas if it is poured colder the chill will not occur. This seems to be contrary to general practice, but nevertheless it is true.

As to the scum which was just mentioned, in general, we believe that soft iron looks more sluggish and more to the orange color than iron which is inclined to be harder.

There is one more point I would like to bring out, that this dry blast was ready for operation about the third last day in May, two years ago. It was ready for operation about nine o'clock in the morning. On this particular day we had started out to have trouble with hard castings very early. The condition evidently was bad, because by 8:30 in the morning we were getting chilled castings.

We turned the dry blast on and in less than fifteen minutes there was a definite line of demarkation on our conveyor separating hard castings on the one side and, on the other side, soft castings.

Molding Practice for Heat-Treated Aluminum Alloy Castings

By Lewis H. Fawcett,* Washington

Abstract

The purpose of this paper is to outline the methods and precautions necessary in the satisfactory production of castings composed of aluminum with 4 to 5 per cent copper. Molding is considered in relation to design, pattern design, cores, gating and heading. Melting and pouring precautions are discussed and heat treating equipment and process are described. Prevention of cracks and checks is considered from molding, core-making and design standpoints. To illustrate the methods discussed, the process of making a housing-frame casting is described in detail.

1. Copper-bearing aluminum alloys present difficulties in molding, due to the relatively high crystallization shrinkage and hot shortness of such alloys. Therefore, special methods or precautions must be employed in the manufacture of castings made of this class of material in order to overcome the effect of these characteristics.

2. On the contrary, an alloy consisting of approximately 95 per cent aluminum and 5 per cent silicon has excellent casting characteristics. Unfortunately, however, the latter composition is relatively deficient in both strength and ductility as compared with a heat-treated aluminum-copper alloy containing 4.50 per cent copper.

3. It is the purpose of this paper to outline the methods and precautions that are necessary in the satisfactory production of castings composed of aluminum with from 4 to 5 per cent copper. In this description the principal topics will be presented in the

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Note: This paper was presented and discussed before one of the nonferrous sessions at the 1931 convention of the American Foundrymen's Association.

following order: Under molding, consideration will be given to the original design of castings, pattern design, molding, core making, and gating and heading; melting and pouring likewise will include handling after pouring; heat treatment will follow, then analyses and mechanical properties, and finally, a specific application.

MOLDING

Design of Casting and Pattern.

4. As far as practical, castings should be designed of uniform cross-section, avoiding abrupt changes from one cross-section to another. Liberal fillets should be employed, round openings are preferred to rectangular ones, and rounded corners also are to be desired.

5. Frequently, patterns that are completely satisfactory for silicon-aluminum alloys are entirely unsuitable for the heat-treated alloy. When practical, patterns should be designed to permit the casting to contract away from cores instead of toward the core.

6. Self-coring patterns for interiors, where practical, are preferable to box cores. For large work, pattern may be designed for use of loam cores in lieu of box cores. Patterns must be so designed that heavy sections will be accessible for the required shrink heads. The use of loose pieces, causing excessive overhang of mold which must be heavily secured, are to be avoided.

7. It also is essential that patterns be accurate to permit the assembly of cores without causing excessive finning on the completed castings.

Venting, Chills, Flasks and Sand Control.

8. The general principles underlying the molding of aluminum-alloy castings apply in the main to the heat-treated alloy, but special precautions must be taken to obtain full success.

9. In green-sand work adequate venting is important, sand control is desirable, molds should be rammed lightly and uniformly and sand worked with slightly less moisture content than is customary in the case of other nonferrous metals. Flasks should not be "barred" any closer than necessary to secure the mold, in order not to obstruct full contraction. Chills are absolutely necessary in large sections inaccessible to shrink heads. Brackets or tie bars often are required to prevent cracking of the castings.

Cores.

10. Special attention should be given to cores for the heat-treated alloy. Cores must be soft and capable of being crushed as the metal contracts around them, so as not to crack the metal as it cools through the hot-short range of temperature. This may be accomplished by the use of collapsible cores, that is, cores that are strong enough to withstand handling and pouring but capable of collapsing after pouring, so as to prevent cracking the casting.

11. It is essential that care be taken in selecting sand binders so as to obtain a binder that will disintergrate at low temperatures. Heavy core rods should be avoided. Liberal use of cinders or crushed coke in the interior of cores is desirable. It is far better to have occasional breakage of cores in handling than to have cores so strong that they cause breakage of the castings.

Gating.

12. It is essential that serious thought be given to gating. The longer the flow of metal from the gate before meeting an obstruction, the cleaner the castings.

13. As a general rule, gates should be designed so that the sprues enter the smaller cross-section rather than the larger cross-section of the casting. By this means the hot metal will be cooled by passing through long, thin sections before it reaches the larger section, resulting in a more uniform grain size throughout the casting. Also, improperly placed gates may restrict contraction by acting as a clamp and causing the casting to crack during cooling.

14. Before inreasing the pouring temperature to run a casting, study should be made to determine if the gates could be improved.

Shrink Heads.

15. More liberal use of shrink heads is necessary with this alloy than is the case with the silicon-aluminum alloy. Round heads are more efficient than rectangular ones. An increase in the height of a head often is more conducive to results than increasing its diameter.

16. In general, however, an increase in the pouring height is not to be recommended, but the desired results may be obtained

by building the shrink heads or risers above the cope, pouring the casting, covering the gate with a weight and then filling the excess head with hot metal. Overflowing of heads during pouring should be avoided, as the fin produced in this manner may restrict contraction and cause the castings to crack or check.

MELTING AND POURING

17. The greater the care taken in melting, to prevent excessive temperature and to avoid foreign material coming in contact with the charge, the more consistent will be the results obtained.

Pouring Temperature Control.

18. Pouring temperature also is of great importance. A general rule that can safely be followed is to pour at the lowest possible temperature that will run the casting.

19. Accurate control of pouring temperature should be employed for two reasons: (1) Low temperatures decrease contraction during solidification, and (2) likewise increase the mechanical properties of the material.

20. At the Naval Gun Factory, the metal is placed in carborundum or clay-graphite crucibles and melted in anthracite-coal-fired, pit-type furnaces. When the temperature of the metal reaches 1300 degs. Fahr., the crucible is withdrawn from the furnace and poured immediately into the molds, the work being scheduled so that the mold and metal are ready at the same time. In this manner the pouring temperature for the average size work is maintained at from 1300 to about 1250 degs. Fahr.

Fluxing and Pouring.

21. Before pouring, the metal should be fluxed with zinc chloride (1 oz. per 100 lbs. of metal) and carefully skimmed. Sprues should be kept choked during pouring and the metal handled quietly without agitation to prevent oxidation and to keep the castings free from dross. The ideal condition to minimize agitation is an unbroken stream poured from a low height.

Alloys.

22. The best results are obtained when the alloy is compounded with the purest grades of commercial aluminum and

copper. Minor constituents must be reduced to the lowest possible extent, for the presence of even small percentages of other elements may cause a great reduction in ductility after heat treating.

23. It also is advisable to make an alloy of 50 per cent copper and 50 per cent aluminum to be used as a "hardener." A representative melt would consist of the hardener with the necessary aluminum addition, plus 40 per cent scrap resulting from a former melt of like composition.

Shaking Out.

24. In the case of intricate work, often it is desirable to remove the casting from the mold as soon as it can be handled, and to "knock out" the cores to allow ease of contraction. Although great care must be taken at this stage to prevent distortion, nevertheless it is considered that the benefits obtained in reducing the chances for checking fully jusify the effort required in careful handling.

25. The above-mentioned precautions are extremely important, due to the previously mentioned hot-short characteristics of this composition. Changes in dimensions of the castings after being removed from the sand are not great. Distortion in molding is not appreciable, provided the above-stated preventive measures are diligently performed.

Fettling.

26. Heads and gates are removed by sawing. The remaining bottom portions of heads then are ground to the level of the surrounding surface. If any fins are present, they are removed by grinding. Afer this operation the castings are ready for heat treatment.

HEAT TREATMENT

Equipment.

27. The equipment used by the Naval Gun Factory for heat treating aluminum-alloy castings consists of an electric resistance furnace, about 6 feet in diameter and 9 feet deep, a quenching tank of the same capacity, and the necessary auxiliary devices. Both the furnace and tank are beneath the floor level and within a few inches of each other.

28. The furnace top, which is only a few inches above the foundry floor, is removed by means of an electric motor. It is lifted slightly and moved sideways to open or close, and when closed it is sand sealed.

29. Heat is obtained from chrome-nickel grids located on the bottom and around the circumference of furnace, the furnace being maintained at plus or minus 2.5 degs. Fahr. of the desired temperature by means of automatic temperature-control apparatus. The temperature control is aided by the fact that the furnace is entirely surrounded by heat-insulating material. Temperature of the water may also be elevated by passing steam through the perforated coils placed on the bottom of the quenching tank.

30. During the heat-treating operations the castings are contained in steel-framed wire baskets. All of the baskets have the same diameter, about 4½ feet, but differ in height. The large size occupies the entire furnace depth, the medium size one-half of the furnace, and the small size one-third of the furnace capacity. Baskets are handled by a jib crane with a 1-ton electric hoist attached.

Distortion.

31. Heat treatment is accompanied by excessive distortion unless the proper care is exercised in securing the castings during the heating period. Castings are heated to 960 degs. Fahr. and held at this temperature for from 18 to 24 hours, depending on their cross-sectional areas. Thus, the heat-treating temperature approaches the melting point of the material, with the result that the castings become soft and will bend and distort unless they are properly supported.

32. To prevent change in dimensions, when the castings are placed in the baskets they are well secured with wire and by wedges placed beneath them. so that they remain in a vertical position.

Heating Castings.

33. The castings also are set in a vertical position on account of the type of furnace being used, namely, an air-sealed furnace in which the heating units are located around the circumference and on the bottom, without any artificial means of circulating this heat.

Consequently, the heat is transmitted to the castings by radiation and, therefore, the castings should be so placed in the baskets that the maximum surface area is exposed to the direct heat rays emanating from the grids.

Quenching.

34. It is essential that the time between withdrawing the casting from the furnace and its subsequent quenching be as short as possible, otherwise the desired mechanical properties cannot be obtained. The equipment, being designed for the purpose, is so efficient that this interval of time is only one-half minute.

35. After quenching, the basket is allowed to remain in the water until the castings have been reduced in temperature to that of the quenching water. The water generally is maintained at a temperature between 150 and 190 degs. Fahr.

36. On being withdrawn from the tank, the castings dry almost immediately, due to their temperature being approximately 100 degs. Fahr. higher than the temperature of the plant. As this is the last stage of the process, the castings are shipped to the machine shop when removed from the baskets.

CHEMICAL ANALYSES AND MECHANICAL PROPERTIES

Aging.

37. Although heat treatment is necessary to produce the desired mechanical properties, on standing at room temperature after being heat treated this alloy will increase in tensile strength and decrease in ductility. This change in properties is called aging.

38. A noticeable amount of aging will take place within a few days after the heat treatment of the material. On this account the specifications require that test bars representing castings made from this copper-aluminum alloy shall age at least 48 hours before being tested. Therefore, the test bars are machined at any time within the 48 hours but are not pulled until the expiration of that period of time.

Specifications.

39. Requirements governing the testing of this material are found in Navy Department Specifications, Aluminum Alloy, Light;

Table 1

COMPOSITION

Designation.	Al	Cu	Si	Zn	Fe	Mg	Mn
Requirements of 46Ala, Cl 4	94.5 min.*	4.0-5.0	1.20 max.	0.25 max.	1.20 max.	0.35 max.	Trace max.
Melt No. 7233R	95.12	4.48	0.21	.....	0.19	.....	0.05†
Melt No. 7463R	94.98	4.73	0.13	.....	0.16	trace	0.05†

*Total of all constituents, other than Cu and Al, 2.5 per cent maximum.
†Less than.

Table 2

MECHANICAL PROPERTIES

Designation	Pouring temp., degs. Fahr.	Diam. of specimen, in inches		Tensile strength, lbs. per sq. in.	Elongation in 2 in. %	Fracture
		As cast	After machining			
Requirements of 46Ala, Cl4	....	.565	.505	28,000	6.0	.....
Melt No. 7233R	1250	.565	.505	36,500	12.5	Irregular
Melt No. 7463R	1220	.565	.505	37,500	17.6	Irregular
Melt No. 8686R	1300	.565	.505	29,500	10.0	Irregular
Melt No. 8710R	1260	.565	.505	35,000	13.2	Irregular
Melt No. 7558R	1220	.565	.505	33,000	8.5	Irregular
Melt No. 7576R	1280	.565	.505	35,000	16.2	Irregular
Melt No. 7636R	1280	.565	.505	31,000	8.7	Irregular (flaw)
Melt No. 7753R	1250	.565	.505	32,500	10.2	Irregular

Castings, 46 Ala, Class 4. The chemical analyses of two representative melts are given in Table 1, and the mechanical properties of several typical cases are shown in Table 2.

40. The low content of minor constituents, as given in Table 1, is a great factor in obtaining the high elongations shown in Table 2. This excess of ductility over the requirements is intended as a margin of safety to counteract the possibility of further decreases in elongation by future aging.

MOLDING A HOUSING FRAME (REPRESENTATIVE CASE)

41. The foundry practice employed in the manufacture of a housing-frame casting, involving some of the precautions outlined previously in this paper, is described hereafter.

42. Pattern, and the drag section of flask, are placed upon a follow board, the follow board being designed to fully support the pattern during ramming. Chills, brackets and a bearing plate are set in their proper positions on the pattern. After the drag is prepared, the cope (which is barred) is set in place on the drag, filled with sand and rammed up.

43. Two gates and eight sink heads are utilized in molding the cope. The usual amount of vents are made over the surface of cope, the cope is then taken off, the pattern removed from the drag, and cope and drag given a workmanlike finish.

44. Molding is preformed in green sand, using No. O Albany heap sand for facing material. Sand is worked as dry as practicable, the moisture content not exceeding 5 per cent. After finishing, the entire mold is sprayed with crude oil to protect chills and eliminate the necessity of adding moisture to sections that may have dried out while dressing.

Many Chills Used

45. Fig. 1 shows a photograph of the drag. The impressions on the right and left edges of the drag are entries or sprues made at the bottom of the gates. Through these depressions in the sand, the metal enters the mold.

46. Fifty-two chills are employed in the bottom of this drag. All of them are made of cast iron with the exceptions of the four narrow, rectangular ones (adjacent to the three most prominent core prints), these being made of copper. If the aluminum-silicon

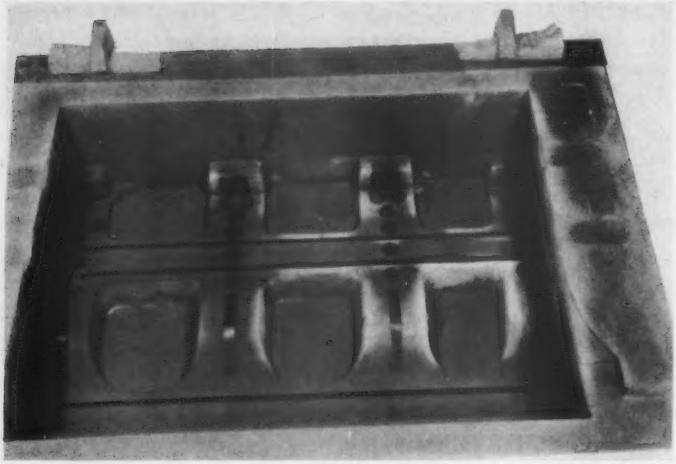

FIG. 1—DRAG MOLD OF HOUSING FRAME. 52 CHILLS ARE SHOWN IN PLACE.

alloy were being used for this job, all these chills would not be necessary; possibly only the four copper ones would be utilized.

47. Three tie bars are visible as impressions extending across the bottom of the mold, while a bearing plate (not visible in the photograph) is located in the foreground forward of and parallel

FIG. 2—COPE MOLD OF HOUSING FRAME, SHOWING RISERS AND SHRINK HEADS.

to the long row of round chills. This plate and the six prominent depressions or core prints furnish the foundation for the three cores used in making the casting.

48. The cope is shown in Fig. 2, with the location of the two gates and the sink heads plainly seen.

Cores Are Fragile to Prevent Cracking

49. Three cores used in molding this casting are shown in Fig. 3. They are made in wooden core boxes which are designed to part, to prevent the necessity of "rolling over," because the cores are purposely of very fragile construction and, while green, are only strong enough to withstand careful handling.

FIG. 3—CORES FOR HOUSING-FRAME MOLD, SHOWING CONSTRUCTION WHICH PERMITS GIVING UNDER PRESSURE OF CONTRASTING CASTING.

50. The interiors of the cores are filled with crushed coke or cinders and rodded as lightly as practicable. After being taken from the ovens, these porous interiors are removed, leaving the central portion hollow as shown in the photograph of Fig. 3.

51. The prints on the bottom of the cores are likewise only a shell, but they are not visible in this picture. There are four steel rods, 1/4 inch in diameter, in the top of each core, one along each edge. The bottom of the cores have the same arrangement of rods, only in this case 3/8-inch diameter rods are utilized.

52. These fragile cores facilitate contraction by crumbling under the pressure of the contracting metal, and thus avoid cracking the casting. Furthermore, they serve as exits for gas and air which may pass through them to vents cut in the top edge of the drag at points near one end of each core.

53. Core sand used in this case consists of a mixture of 120

parts straight silica sand and 1 part oil by volume, a good linseed-oil substitute being used for this purpose. The sand is passed through a No. 10 sieve before the oil is added. After adding the oil, the core sand is carefully tempered with water and mixed thoroughly in a mechanical paddle mixer.

54. While resting on a cast-iron core plate, the core box is removed from the core, thus allowing the core to be transferred to the core ovens on this plate. When removed from the oven, the cores are painted, while warm, with wet blacking. The heat of the core quickly dries the blacking and the core then is ready to be set in its place in the mold.

SETTING CORES, CLOSING MOLD AND POURING

55. When the cores have been set in place in the drag, the mold then is closed and poured immediately. Two crucibles are used in pouring, each containing about 75 lbs. of metal, pouring being accomplished simultaneously through the two gates, the pouring temperature being 1280 degs. Fahr. After pouring, the heads and gates are relieved by removing the sand from around them so that they may be free to move as the casting contracts and thus facilitate rather than retard the contraction of the casting.

56. Fig. 4 is an illustration of the drag with cores assembled therein, or, in other words, with the mold ready to be closed. In the background, hardly visible in the photograph, three vents have been cut in the edge of the mold adjoining the end of each core to

FIG. 4—CORES IN PLACE IN DRAG MOLD.

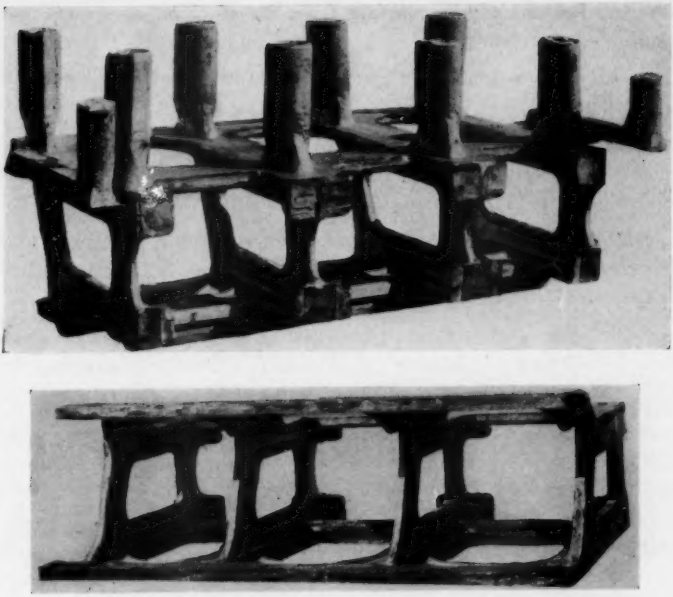

FIG. 5—HOUSING-FRAME CASTING. *A* WITH GATES AND RISERS STILL ATTACHED. *B* WITH GATES AND RISERS REMOVED AND CASTING UPSIDE DOWN AS COMPARED WITH *A*.

FIG. 6—TEST BARS CAST IN GREEN SAND, SHOWING FOUR BLIND HEADS AND CENTRAL POURING GATE.

allow the escape of gas and air from the interior of the cores, as mentioned previously.

57. Fig. 5-*A* shows the casting before the heads and gates were removed.

58. Fig. 5-*B* is a photograph of the finished casting taken from the opposite side and in a position upside down as compared with Fig. 5-*A*. This casting is about 11×21×34 inches.

59. Fig. 6 gives a picture of the type of test bar used, made in green sand with two specimens per flask. Attention is directed to the four blind heads and the central pouring gate.

60. Fig. 7 shows the heat-treating equipment. The furnace with its lid removed is shown on the left, while the quenching tank with a basket half submerged may be seen on the right.

61. Castings manufactured as outlined in this paper are subjected to rigid surface inspection, in addition to inspection of the chemical and mechanical requirements. They must also be accurate in their dimensions and sound throughout, so that a serviceable article will be the ultimate result.

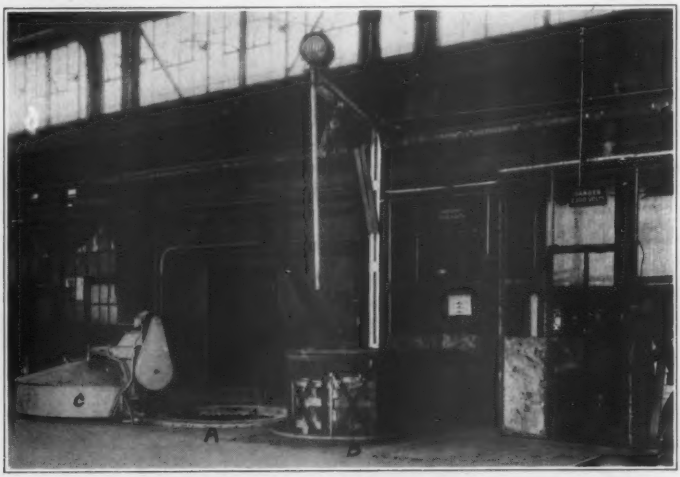

FIG. 7—HEAT TREATING EQUIPMENT. FURNACE (*A*) SUNK IN FLOOR WITH LID (*C*) SWUNG TO LEFT. QUENCHING TANK IS SHOWN AT *B* WITH BASKET OF CASTINGS BEING SUBMERGED FOR QUENCHING.

DISCUSSION

W. F. GRAHAM:[1] What is the method of removing the risers from the casting shown in the paper—the equipment or the method used?

J. E. CROWN:[2] The risers were removed with a band saw.

A. J. FIELD:[3] I would like to ask Mr. Crown if he can tell us anything about the core sand and mixtures that he used, if he has any further information as to the quality of the foundry sand he used, and whether any special facings were used. Also, I would like to know what his practice is with respect to the use of the mold in the green condition—whether it was skin dried or dried in any way.

J. E. CROWN: Answering Mr. Field's first question, it is necessary to use several core-sand mixtures on the castings described in the paper. One of these mixtures is cited as having an oil ratio 1 to 120. That was for an extremely delicate job. The core had to be handled with extreme care, as the core would practically rub away with rough treatment. For castings having a fairly heavy section, the mixture of sand is about one-third of sharp silica sand—not a washed sand, but having about 13 per cent clay similar to that called a natural bond sand in steel. The remaining two-thirds is a straight Albany sand used for molding, or from crushed cores from previous castings. That is mixed with an oil binder substitute for linseed oil, usually in the proportion of about 1 to 50, or 1 to 60.

Referring to the question about drying, the molds are poured green for the majority of light work. However, where a casting requires a large number of chills and there is quite a time interval between the placing of the chills in the mold and the setting of the copes, and the actual time of pouring, it is our practice to spray the mold with a crude oil and then quickly skin dry the surface with a flame torch, close the mold and pour while the mold is still warm, in order to prevent moisture from being absorbed by the chills.

A. J. FIELD: Do you use any sort of facing on the mold, or do you just pour in the sand?

J. E. CROWN: We use no special facing on the mold. We are using the No. O Albany sand; the entire heap is of this sand.

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[1] Technical Director, Caskey Brass & Bronze Co., Philadelphia.
[2] Master Mechanic, Foundries, U. S. Naval Gun Factory, Washington.
[3] Sales Engineer, British Aluminium Co., Ltd., New York.

Related Class-Room Training for Foundry Apprentices

By S. M. Brah,* Moline, Ill.

Abstract

Acting upon a request of the A. F. A. Committee on Apprentice Training, the author made a survey of related instruction being given foundry apprentices in plant and municipally conducted training courses. The data collected are presented in tabular form for the guidance of those who wish to organize such courses. The survey reports on the amount of time spent on instruction in related subjects, the type of courses covered, costs of conducting courses and other factors of importance. The author then discusses these various factors.

Introduction

1. Apprenticeship has been defined as the training of the hand and mind in the science of a craft or trade. While apprenticeship laws have always required that the master teach the apprentice the entire trade and provide necessary schooling, there was no interpretation as to what "necessary schooling" should include. The purpose of this paper, then, is to discuss this school training.

2. We can assume that everyone agrees that a well-organized apprentice training program should include some school work, but there is little or no agreement, even among educators themselves, as to what the curricula of the apprentice course should contain. The writer sent out questionnaires to more than one hundred

* Apprentice Supervisor, Tri-City Manufacturers' Association.

Note: This paper was presented and discussed before the session on apprentice training at the 1931 convention of the American Foundrymen's Association.

plants and communities to collect data on class-room training for apprentices.

3. The difficulty found in compiling even this crude and unfinished sketch of the situation, and the general interest shown in the problem during collection, indicates the need for continuous collection and thorough study of facts of this nature by everyone associated with the training of apprentices.. We wish here to quote a statement made as follows:

> "The chief argument in favor of the continuous education of the apprentice, even those who have completed high school, is that the boys are not intellectual camels who can take their education in a prolonged meal —an educational gorge—store it up in an educational hump and live off the hump all the way across the desert of life. It assumes that the school is able, by itself, to furnish a balanced ration. It disregards entirely the law of decreasing returns from one type of activity—the law of satiety of appetite, and the value of exercise in restoring the appetite. It overlooks the possibilities of making education, even school education, a continuous, life-long process, satisfying naturally a normal appetite."

Problems of the Apprentice School

4. It becomes increasingly evident that the curricula of the apprentice school must be widely varied in nature, and to add to this difficulty only one teacher usually is available to instruct the group in all branches.

5. In addition, the teachers of these classes are faced every day with new problems which make demands on all their resources. These problems, with pupils in various periods of life, previous training and mental capacity, demand teachers of exceptional qualifications as to personality, experience and training.

6. For academic and related subjects, it is necessary that the teachers should have had, if not actual industrial experience, at least close contact with industry, and that they should be close and interested students of industry and industrial conditions generally. However, another thing also is essential (although sometimes overlooked), that is, a knowledge of the subjects they are to

teach—a knowledge so thorough that the teachers will be free to give their attention to the pupils and their individual needs. No amount of personality or good intentions can take the place of thorough training for whatever subjects are to be taught.

7. The class-room training should cover the same period as the shop course and not be condensed into two years or less, which makes the training given dependent upon deferred values for its justification.

8. Many schools are laboring under a very natural but unfortunate handicap. Methods established in the regular full-time schools have carried over to this part-time system. Apprentice classes should be open so that students can be enrolled at any time, and the text material and methods of instruction should be such that each student can proceed at the rate dictated by his previous training and mental capacity.

9. The material should be so prepared that it is entirely self-explanatory or as nearly so as human efficiency can make it. This will enable the class-room supervisor to permit each student to work on such subjects as he is at that time engaged in at the shop. Thus, if he is working on the cupola, he should be studying the cupola and its operation.

10. This qualification prohibits carrying the class as a group, which should be discouraged for the aforementioned reasons. From data at hand, we are forced to believe that under many of the established systems, the above conditions cannot be met.

11. The school shop or place of work, fitted with the equipment and materials of the shop, is too costly to be demanded of the small employer or poorer school districts. The same results can be achieved through shop training entirely.

12. The ability of these pupils to do thorough work and digest a wide variety of mental diet has been proven in a few isolated programs. We need have no fear for the inferior mentality of the apprentice from those who go on through high school or college. Many of our apprentices are high school graduates, which in itself is a stamp of their mental qualifications, and in no case does the writer know of a program that welcomes those mentally slow or deficient.

13. The writer is of the opinion that the problem of the apprentice course is to offer variety *of the right kind.*

Studies of Apprentice School Curricula

14. The data collected have been segregated under two classifications, "Municipally Conducted Continuation Schools" for foundry apprentices (Table 1), and "Plant-Operated Classes" (Table 2).

Mathematics

15. Abstract mathematics of elementary grade is offered in most classes, and it affords a much-needed opportunity to review this subject. The practical application of elementary mathematics is offered without exception and should form the major portion of this course. Trigonometry and geometry are offered in several schools and shops, and it has a limited use in foundry practice.

16. Algebra, however, has difficulty in justifying itself in a foundry apprentice course for its practical value. The writer has failed to find the need for this subject in the solving of practical foundry problems. An interesting point to note is that from those schools reporting, algebra is offered by more plant classes than municipally conducted schools.

17. Coordination between the mathematics and related information should exist to firmly establish the principles involved in the student's mind. The amount of time spent on mathematics will be determined by the apprentice's mental capacity, rather than by some standard established by regular school practice.

Science

18. The need for science in the form of selected chapters of a physics course, and the fundamentals of chemistry, is almost universally recognized. In some cases, the science course has been substituted in place of related information. While it has much practical value, it is somewhat indirectly related.

19. One school teaches social science, while a shop class offers physiology. Both subjects have merit and, if sufficient time is available, the introduction of these subjects is to be encouraged.

Economics

20. The need for economics was forcibly brought to the attention of the writer while conducting classes a number of years ago. An apprentice, employed by a large corporation with sev-

Table 1

MUNICIPALLY CONDUCTED CONTINUATION SCHOOLS

Name and Location of Classes	No. of classes	Total attendance	No. of teachers*	No. of meetings per week—hrs. per meeting	Practical instruction in school	Cost of equipment	Cost of classes per pupil, teacher and texts	Students paid for attending	Students pay for attending	School expense paid by	Administration by
†Vocational School, Beaver Dam, Wis.	1	10	I	1/4	Yes	$1,000	$6.40 per hr.	No	No	School dist.	Voc. board
Vocational School, Birmingham, Ala.	1	15	P	2/3	Yes	Furnished by plant		Yes	No	Manufacturer	Board of Education and plant
State Trade School, Bridgeport, Conn.	2	23	F	/8	Yes	$11,000	12c per student hr.	Yes	No	State and federal funds	State board of education
Trade School, Chattanooga, Tenn.											
Cleveland Trade School, Cleveland, Ohio	2	40	2 F	5/6	Yes	$15,000		Yes	No	School dist.	Voc. committee
†Vocational School, Cudahy, Wis.	1	9	I	1/4	No		$7.00 per hr.	Yes	No	Voc. school dist.	Voc. school board
Public School, East Chicago, Ind.	4	43	3 I	1/4	No		Texts and drawing eqpt., $40. Teacher, $.224 per pupil hr.	Yes	No	School dist., manufacturers and state	School dist., manufacturers and state
†Vocational School, Fond du Lac, Wis.	1	5	I	1/4	Yes	$500	$13 per mo. per pupil	Yes	No	Voc. school dist.	Voc. school board
Harvey Township High School, Harvey, Ill.	1	1	P	1/4				Yes	No	School dist.	School board
Vocational School, Milwaukee, Wis.	10	150	2 F	1/4	Yes	$15,000	(No data)	Yes	No	Voc. school dist.	Voc. school board
Cooperative School, Newton, Iowa	1	6		Half time			(No data)	No	No	School dist.	School board
Trade School, Providence, R. I.	1	25	F	5/1	Yes			No	No	School dist.	School committee

See footnotes on page 317.

(Continued on next page)

Table 1 (Continued)

High School, Rockford, Ill. (1 class full time, 1 class coop., 1 group of apprentices)	3	48	3 P	1/4 (apprents.)				Yes (apprents.)	No	School dist.	School board and advisory committee
Gustings Tech. High School, Terre Haute, Ind.			2 F	5/4	Yes	$1,000	$40 per pupil	No	Yes (supplies)	School dist.	School board
†Vocational School, Waukesha, Wis.	2	8	I	1/4	Yes	$200	$16 per mo. per pupil	Yes	No	Voc. school dist.	Voc. school board
Apprentice Vocational School, Moline, East Moline and Rock Island, Ill.	3	30	I	1/4	No		$.28-1/2 per student hr.	Yes	No	School dist.—state and federal funds	Educational comm. of manfrs., supt. bd. of education and supt. apprent. training

*F—Full-time instructor; P—Part-time instructor; I—Itinerant instructor.

†These classes are conducted by the same itinerant instructor.

(Continued on next page)

Table 1 (Continued)

MUNICIPALLY CONDUCTED CONTINUATION SCHOOLS

Name and Location of Classes.	Mathematics.	Science.	Economics.	Civics.	Drawing or blueprint reading.	Related information.	Miscl. shop talks, movies, trips, etc.
*Vocational School, Beaver Dam, Wis.	Elementary math.[1]	Physics and chem.[1]	Costs			Molding, core making, melting, cleaning and other trade processes[1]	Shop visits, 2 each yr.
Vocational School, Birmingham, Ala.	Trade math.				Drawing, tracing, blueprint reading		
State Trade School, Bridgeport, Conn.	Trade math.[1, 2]	Physics and chem.[1, 2]	Costs		Blueprint reading, sketching	Molding, core making, melting, cleaning and other trade processes [1, 2, 6]	Shop talks, field trips
Trade School, Chattanooga, Tenn.	Evening classes (no information)						
Cleveland Trade School, Cleveland, Ohio	Shop math.	Foundry technology	Industl. econ.	Yes	Drawing	Foundry practices	Shop talks and visits, movies
*Vocational School, Cudahy, Wis.	Elementary math. [1]	Physics and chem.[1]	Costs		Elementary mech. drawing and blueprint reading	Molding, core making, melting, cleaning and other trade processes [1]	Shop visits, 2 each yr.
Public School, East Chicago, Ind.	Elementary math. and trade problems[3]	Physics and chem., high school	Shop organization		Geom. and mech. drawing, blueprint reading, sketching[3]	Molding, core making, melting, cleaning and other trade processes; equipment, metallurgy [3, 5]	Movies, shop visits
*Vocational School, Fond du Lac, Wis.	Elementary math. [1]	Physics and chem.[1]	Costs		Elementary mech. drawing and blueprint reading	Molding, core making, melting, cleaning and other trade processes[1]	Shop visits, 2 each yr.
Harvey Township High School, Harvey, Ill.	Related shop math.				Core box drawing		
Vocational School, Milwaukee, Wis.	Fundamentals of arith., trade arith., algebra and applied geom.	Metallurgy, industl. chem. and physics	Principles of econ.	Citizenship	Fundamentals of shop drawing and blueprint reading	Matls. of construction, trade and foundry technology, practical mech., safety	Safety, hygiene, English

See footnotes on page 319.

(Concluded on next page)

Table 1 (Concluded)

Cooperative School, Newton, Iowa	High school math.	High school chem., physics and soc. science	Shop organization	English	Shop drawing	Molding, core making, melting and cleaning room practice [2]	Movies, shop talks each Sat. A. M.
Trade School, Providence, R. I.			Same as Massachusetts Institute of Technology				
High School, Rockford, Ill., (1 class full time, 1 class coop., 1 group of apprentices)	High school math., shop math.[4]	Elementary science[4]	Elements of citizenship[4]		Mech. drawing[4]	Foundry practices[4]	Safety talks, shop talks, movies, shop visits
Gustings Tech. High School, Terre Haute, Ind.	Shop math.	Applied science	Industl. hygiene	Voc. civics, English	Mech. drawing, blueprint reading, sketching	Voc. guidance, wood pattern making	Visits to foundries, shop talks, movies
*Vocational School, Waukesha, Wis.	Elementary math.[1]	Physics and chem.[1]	Costs		Elementary drawing, blueprint reading	Molding, core making, melting, cleaning and other trade processes[1]	Shop visits, 2 each yr.
Apprentice Vocational School, Moline, East Moline and Rock Island, Ill.	Elementary math., geom., trigonom., algebra, gear calculations and trade problems[3]	Industl. physics; elementary chem.; metallurgy—mixing, cast iron	Industl. econ., shop organization		Mech. and geom. drawing, blueprint reading, sketching	Molding, core making, melting, cleaning and other trade processes; equipment and metallurgy [3, 5]	Movies, shop visits, talks, conferences

*These classes are conducted by the same itinerant instructor.

TEXT USED:
1. "Elementary Foundry Technology," by L. A. Hartley, 1928.
2. "Foundry Work," by R. E. Wendt.
3. International Correspondence Schools foundry books.
4. All text material prepared by instructors.
5. Trade journals, assigned readings, A. F. A. TRANSACTIONS.
6. *The Foundry*, Cleveland.

eral plants widely separated and with a large parent company organization, remarked that the president of his company "had little or nothing to do as he had so many assistants to do the work for him while he worked alone." In a few words, he was convinced that he, too, had many assistants to bring material to him and carry it away, to furnish light, heat and power and generally aid him in the manufacture and selling of their product.

21. In another instance, an apprentice working in the foundry of a plant went to the office to purchase a gear which he was at that time engaged in making in the foundry. He was paid 4 cents per mold which contained 6 gears, or at the rate of ¾ cents per gear. When he was told the price was 84 cents, he could not reconcile this markup with his meager knowledge of economics.

22. Economics has a very definite place in any training program today, for no better means of establishing the importance of economy and efficiency exists than in the lessons in the principles of economics that treat with value, organization and overhead.

Civics

23. Very little emphasis has been placed on civics. The survey shows but five schools, either plant or municipally conducted, teaching this subject. Citizenship, incorporating the rights and duties of the citizen, form the outline for this course.

Drawing

24. Drawing and blueprint reading have been grouped under one heading because of their natural relationship.

25. Geometric and mechanical drawing have well-defined values to the foundry apprentice. The danger lies in overemphasizing the importance of this subject by providing too extensive a course. Danger of creating a desire in the apprentice to leave the foundry for the drafting room, often when he is not capable of developing into a draftsman, follows this practice.

26. The fundamentals of drawing can be taught in a relatively short period of time. Sketching has a more immediate and practical value to the foundryman and should unfailingly be included in the drawing course. It lends itself to a wider field of drawings in the same period of time and teaches the principles as well.

Table 2

Plant Operated Classes

Name and Location Classes	No. of classes	Total attendance	No. of teachers	No. of meetings per week—hrs. per period	Practical instruction in school	Cost of equipment	Cost of classes per pupil, teacher and texts	Students paid for attending	Students pay for attending	School expense paid by	Administration by
American Steel Foundries, Granite City, Ill.	4	25		1/4	No	$900	$75—for 4 yr. course	Yes	No	Manufacturer	Voc. board
Bausch & Lomb Optical Co., Rochester, N. Y.					No			Yes	No	Manufacturer	
Brown & Sharpe Mfg. Co., Providence, R. I.	2	20	1	1/2	No			Yes	No	Manufacturer	Plant and supervisor of apprentices
Caterpillar Tractor Co., Peoria, Ill.	1	22	1	1/4	No	Unknown	Unknown	Yes	No	Manufacturer	Supervisor of plant training
Clark Bros. Co., Olean, N. Y.	2	18	1	1/4	No			Yes	No	Manufacturer	Supervisor of training
Ford Motor Co., Detroit, Mich.	2	50	3		Yes			Yes	No	Henry Ford trade school	Trade school
General Electric Co., West Lynn, Mass.			6	5/1-1/4	No			Yes	No	Manufacturer	Educational committee
General Steel Castings Corp., Commonwealth Division, Granite City, Ill.	24	300	6	5/2-1/4	No	Unknown	Unknown	Yes	No	Manufacturer	Educational director of corp.
International Harvester Co., Fort Wayne Plant, Chicago, Ill.				1/4	No			Yes	No	Intl. Harvester Co.	Supervisor
Lynchburg Foundry Co., Lynchburg, Va.	3	26	3	5/1-1/2	No			Yes	No	Local school board, State voc. board	Manufacturer
Newport News Shipbuilding & Dry Dock Co., Newport News, Va.	30	216	33	2/3	No			Yes	No	School dist.—7% Company —93%	Supervisor of training
Singer Mfg. Co., Elizabethport, N. J.	1	6	3	3/1-1/2	No		$59	Yes	No	Manufacturer	Plant committee
Yale & Towne Mfg. Co., Stamford, Conn.	1	4		1/4	Yes			Yes	No	Manufacturer	Director of training schools

(Continued on next page)

Table 2 (Continued)

PLANT OPERATED CLASSES

Name and Location of Classes.	Mathematics.	Science.	Economics.	Civics.	Drawing or blueprint reading.	Related information.	Miscl. shop talks, movies, trips, etc.
American Steel Foundries, Granite City, Ill.	Elementary math. with related shop problems [8]	Elementary chem., metallurgy; mixing cast iron; mech. principles	Industl. economics		Mech. and geom. drawing; sketching and blueprint reading	Molding, core making, melting and other trade processes—equipment and sand test [2, 8]	
Bausch & Lamb Optical Co., Rochester, N. Y.	Math. with shop problems	Physics	Economics		Mech. and geom. drawing	Matls. of construction, trade tech., practical mech.	
Brown & Sharpe Mfg. Co., Providence, R. I.	Elementary math.[9]				Drawing from models and specifications	Estimating, foremanship, English (optional)[9]	Regular schedule of shop talks
Caterpillar Tractor Co., Peoria, Ill.	Math. with shop problems[9]	As applied in foundry and laboratory			Mech. drawing[6]	Metallurgy of iron, steel as applied to foundry and foundry laboratory [10]	
Clark Bros. Co., Olean, N. Y.	Math. (to 288 hrs.) No text books used	Science as covered in text [1] (96 hrs.)	96 hrs.	No	Mech. and geom. drawing (192 hrs.)	Molding, core making, melting and other trade processes—equipment and sand test [7]	Regular talks, safety and shop
Ford Motor Co., Detroit, Mich.	Elementary math., algebra, geom., trigonometry	Physics, chem., metallurgy, metallography	Industl. econ.	Yes	Mech. drawing	English, shop theory, commercial geog., auto mech.	
General Electric Co., West Lynn, Mass.	Elementary math.; algebra, geom. and mensuration	Chem., gen. physics, metallurgy	Shop econ.	No	Mech. drawing	Business English, Foundry materials	
General Steel Castings Corp., Commonwealth Division, Granite City, Ill.	Algebra, geom., trigonom.	Physics, gen. science, physiology	Industl. econ.	Yes	Mech. and geom. drawing	Industl. history, shop theory, English [11]	
International Harvester Co., Fort Wayne Plant, Chicago, Ill.	Elementary math.—use of the formula; trigonom.—slide rule				Drafting and blueprint reading	Shop problems of various kinds	

See footnotes on page 323.

(Concluded on next page)

Table 2 (Concluded)

Lynchburg Foundry Co., Lynchburg, Va.	Elementary math.; algebra, shop geom., trigonon.[3]	Physics, mechanics, foundry chem.[2]			Mech. and geom. drawing, projections	Gen. English, foundry technology [2]	
Newport News Shipbuilding & Dry Dock Co., Newport News, Va.	Elementary math.; algebra, trigonom.[4]	Gen. science and physics [5]	Combined with English		Engineering drawing, shop sketchg.[7]	Foundry technology, English(shop)[1]	
Singer Mfg. Co., Elizabethport, N. J.	Elementary math.	Levers and pulleys			Projections, developments, designing casting layouts	Shop theory	None
Yale & Towne Mfg. Co., Stamford, Conn.	Elementary math.; algebra, geom., trigonom.; shop problems						Shop talks on equipment, safety methods, etc.

TEXT USED:
[1] "Elementary Foundry Technology," by L. A. Hartley.
[2] International Correspondence Schools text.
[3] Palmer's "Practical Mathematics."
[4] Palmer's "Shop Arithmetic"; Wells' "Essentials of Algebra"; Robbins' "Plane Trigonometry."
[5] Millikan and Gale's "First Course in Physics."
[6] Swenson's "Essentials of Drafting."
[7] French's "Essentials of Drawing."
[8] Trade journals and A. F. A. TRANSACTIONS.
[9] Company has own texts.
[10] Composite of several books picked by instructor.
[11] Standard high school text and general library.

27. While there are some that claim blueprint reading is taught synonomously with mechanical drawing, it is apparent that more ground can be covered in a shorter period of time in blueprint reading than in mechanical drawing and is to be preferred if time is precious. The blueprints studied often will be of a more practical nature than the drawings made in the class room, and if the blueprints are gathered from the various shops in the community, they will portray the methods and symbols used in practice.

Related Information

28. At this time, it may be well to define "related information." It is that information which is directly related to trade processes and practices, and differs markedly from auxiliary information and abstract mathematics, science, drawing and the like, in that the latter are only indirectly related.

29. The municipally conducted schools, as reported, offer very thorough courses in molding, core making, melting, cleaning and other trade technique, more often than the plant operated school.

30. While the training in the shop may be thorough and modern in every respect, no single shop incorporates every known device or process as illustrated in the courses and texts used in many of these classes. Also, the foremen, instructors or other employees often are too busy and not well enough informed on some of the points raised by the apprentices.

31. The well-organized course contains detailed information on green-sand molding, including various types of machine molding, core making, dry-sand and loam molding, mixing cast iron, cupola practice, elements of chemistry, foundry chemistry, metallurgy of iron and steel, foundry appliances and equipment, heat treatment of iron and steel, and information relating to materials used, as well as methods of testing raw materials and finished products.

32. Due to the many changes and additions in processes and equipment and methods of testing, it becomes necessary to supplement any test with trade journals and the *Transactions* of the American Foundrymen's Association. Catalogs and hand books have a definite place in this department of the school, for much pertinent information regarding certain types of equipment and

its proper functioning depends upon the close following of certain rules of operation.

33. It is true that much of the information contained in trade journals and the *Transactions* of the A. F. A. is somewhat advanced, but they should be readily assimilated by the apprentice who has completed the course of study as herein described. This does not imply that the beginner should not be encouraged to read these publications as well as his advanced brother.

Miscellaneous

34. Again, our attention is called to the comparative lack of interest among plant-operated classes for extra curricular activities. Various municipal schools offer movies of shop processes, talks on safety and industrial subjects, and a number of visits to other industries. The value of these variations from regular class-room routine may be intangible, but experience has proved that they materially aid the instructor to hold interest and broaden the training of the apprentice by making additional assignments of outside study.

35. Apprentices can be used in many cases to make researches of minor proportions, to gather data for use in the class room and to check various formulas originated from time to time against actual practice in an individual shop or the community as a whole.

36. Contests should be arranged in academic as well as in practical work, in order to stimulate the interest of the student. While the winners of the annual molding contests are to be commended, no one believes they are the outstanding apprentices, taken from every consideration. Others may be more capable to assume supervisory or executive responsibility, due to superior background gained through academic study.

School Administration

37. In almost every case the apprentice is paid for attending school. This practice is commended as the most practical, and certainly it is a very fair one to the apprentice. It enables the employer to demand attendance and set standards of quality and quantity of work done.

38. However, turn about may be fair play in this case, as in

others—the apprentice may also be required to pay something toward his schooling. Wherever this is the case, we find that it is confined to cost of materials and supplies used in class room.

39. Among the municipally conducted apprentice schools, we find a reluctance to invite the manufacturer to assist in the administration of the school. This seems unfair; the interest of the manufacturer is vitally involved. He usually is one of the largest tax payers in the community, and the responsibility for the welfare of the apprentice has been placed upon the employer under the old apprenticeship laws and by recent legislation.

CONCLUSIONS

40. Progressive in many fields of apprenticeship education, one large industrial city reporting asks for proof of the need for foundry education. It is regrettable that large foundry centers in many cases do not support part-time schools for foundry apprentices.

41. The moral responsibility of the public system of education is to provide for the educational needs of everyone in the community. While legislation limits the extent of this service in some states, we find that when there exists a desire to serve on the part of the board of education, ways and means are found to overcome this obstacle.

42. Society as a whole has to pay the bill for labor inefficiency. Half-trained or poorly trained workers in any field increase production costs which, in turn, are passed on to the consumer. A well-organized apprenticeship program should include both shop and class-room training along the lines advocated in the bulletin, *Standards for a Four Year Foundry Apprenticeship,* published jointly by the American Foundrymen's Association and the National Founders' Association, both of Chicago.

43. Any plant or school district desiring to work out an effective program for apprentice education should avail itself of the services of the advisory committees of the above-named organizations or the departments of Vocational Education of its own state, or the federal government.

44. Acknowledgement is hereby made to the bulletin "Apprentice Education," issued by the Federal Board for Vocational Education, for suggestions contained in its contents.

DISCUSSION

CHAIRMAN C. J. FREUND:[1] There has been a tendency among foundrymen to feel that all their problems can be solved exclusively by the introduction of machinery, by the mechanization of the industry. We hold that this tendency is futile and the opinion false. We believe that no matter how highly mechanized an industry or a shop may become, there must be skilled, trained men to supervise and operate that machinery and those mechanisms.

Perhaps some of those present heard the talk given over the radio recently by a well-known economist, discussing the causes (as economists will) of the present depression. Although I did not think that the body of his remarks contained much of value which I had not heard before, his last sentence so impressed me that when the program was over I jotted down his final remarks.

"Of course," he said, "fundamentally the cause for our depression is the fact that we have been too much interested in plants and in mechanisms and in materials and processes, in accounting and in finance, and we have neglected, as a result, the good old-fashioned training of men. We have not, in the United States today, developed enough men to handle the tremendous industrial institutions we have on our hands."

We believe that these incidents illustrate one of the great problems of the foundry industry. The foundry industry has its difficulties, the same as every other industry and probably more than most. Perhaps if one traces those difficulties back far enough through their immediate and semi-immediate causes, it will be discovered that the ultimate cause for all of them is the fact that not enough trained men have been produced by the industry.

Men are the most important factor in this industry. We want to dedicate this session to that principle. Our committee holds it as its most fundamental principle.

This is a difficult idea to put over. The average foundryman is a great deal more interested in sand and molding machines and conveying apparatus and so on. That is natural, because these are tangibles; they are things that he can see and feel, and he can watch them work and operate.

They have a sensible appeal, whereas apprentice training, the development of personnel in one way or another, is vague and difficult to conceive and handle, difficult to understand and difficult to work with. For that reason it does not make the same appeal to foundrymen, and foundrymen are apt to neglect that phase of their business.

S. M. BRAH:[2] Heretofore the A. F. A. has had little or nothing to do with class-room or academic instruction of apprentices, in any way. I will confine myself to a few remarks not included in the text of my paper on this subject.

Related foundry instruction or class-room instruction for foundry

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[1] Apprentice Supervisor, Falk Corporation, Milwaukee.

[2] Apprentice Supervisor, Tri-City Manufacturers' Association, Moline, Ill.

apprentices too often is considered an accessory to an apprenticeship program. To my mind it is an accessory to about the same extent that the automobile manufacturer calls the ignition system and carburetion system of his automobile an accessory. Neither is an accessory; they are all fundamental necessities for the correct and successful operation ot both the automobile and the apprenticeship program.

The particular class-room work for apprentice training introduces some very serious problems which must be solved. Among the most difficult problems are those of overcoming previous traditions in class-room conduct.

Schools—regular academic schools—have been going on in very much the same manner for many, many years, and educators and state directors insist that apprentice schools should follow very much the same procedure in related vocational cases. They do not take into consideration the different type of personnel involved and the different stresses placed upon the subjects at hand. If one can do away with the state to start with, then one of the most serious problems of class-room technique will be overcome.

Text material, too, is a very serious problem, in that much of the text material designed for the regular class-room work for full-time high school students is not entirely adequate for the problem at hand.

Then, too, teachers with little or no experience in compiling text material too often will undertake to write a complete course, including subjects with which they are not thoroughly familiar. One outstanding illustration within my own experience will indicate this problem.

Five years ago I went to the Tri Cities purely on a promotional program. We hired a man to carry on the program—a man who was qualified to instruct, with six years of teaching experience in a state university shop-instruction department. He made the statement that he could write better text material than we asked him to use, and for less money. This is the one thing I wish to emphasize: We were teaching fourteen different trades, and this man had the boldness to say that he could write better instructional material in fourteen different trades than experts in those lines could compile.

Many firms have asked their apprentice supervisors to do likewise—why, I do not know, because in several instances those same firms have called attention to the fact that it is foolhardy for the customer to attempt to manufacture a line similar to their own, a line in which they have spent many years of experience in developing. Nevertheless, they feel qualified to go into the publishing business with absolutely no experience.

Mathematics forms the background of practically all apprentice courses. It is called "related instruction" in some cases, and it is related, indirectly. For the purpose of discussion, I say "indirectly" because we have another phase of instructional material which I call related information, which is directly related to the trade processes and practices carried on in the foundry itself.

In addition to elementary and advanced mathematics, we have been teaching algebra, although in our own case we have decided to drop this subject for lack of practical application.

Science, like mathematics, requires a certain amount of background. Accordingly, we teach both abstract science and abstract mathematics as well as shop mathematics (the latter having gained considerable prominence in the last few years) in order that we may be sure the student understands and will be prepared to cope with the problems to follow.

We teach economics, as do a number of other districts (as shown in Tables 1 and 2 of my paper). I believe this subject has a very definite place. Two illustrations of this are given in my paper, to which I will add a third illustration.

We have a number of foremanship training groups in our district, and in the informal discussion which followed one of these conferences, one of the foremen of a large organization agreed that his particular company should pay out all its reserves, or at least a good share of its reserves, to maintain continuous wages and continuous working conditions in the plant. He argued erroneously that the reserves were part of the wages of labor withheld, not being familiar enough with the principles of economics to know that the reserves are not part of the wages of labor but a part of the wages of capital withheld.

Obviously, if foremen have ideas of this nature, the apprentices they teach also will be brought up with similar ideas. To overcome such a condition, economics can well be introduced to advantage in the apprenticeship course.

With regard to drawing, this subject has a well-defined place in classroom work. However, its kin, blueprint reading and sketching, have a more practical application than the formal mechanical and geometrical drawing.

I should like to define related information as that information which is directly related to the trade practices and processes involved. Science and economics and mathematics are indirectly related.

In a few cases, men who are familiar with a book written by Professor Selvedge, one of our renowned educators, feel that it is their duty to write instructional material. However, in the course of a conversation I had with him, Professor Selvedge stated that he only meant that the shop instructor should write supplementary instruction sheets rather than the complete text material.

With regard to extra-curricular activities, we find—particularly at a time like the present, when it is difficult to give apprentices full-time employment—that extra-curricular activities form a vital part of the program and help keep up apprentices' interest until times are such that we can resume full-time employment.

School administration also is mentioned in the paper. We find, from the data submitted in answer to our questionnaires, that in very few cases are the manufacturers asked to sit in with the school boards or school districts in preparing a program of the sort with which my paper deals.

In conclusion, I would like to say that progress has been made in apprenticeship methods of education, as well as in the number of apprentices employed and the plants employing apprentices. Many district plants, however, have not yet entered upon this particular work, and I hope the

members of this group will return to their districts and help promote apprenticeship.

CHAIRMAN C. J. FREUND: I suppose that school instruction, as Mr. Brah has said, is much more important in an effective apprentice training program than most people realize, even those who are most intimately connected with the work.

W. F. SIMON:[2] I hope that everyone here will take home Mr. Brah's paper and study it. A great deal of work has been put into it, and I have only one serious criticism to make—he is about fifteen years ahead of the times.

There is a great need for related foundry instruction. One of the greatest difficulties in most crafts lies in finding men qualified to act as instructors in the factory. A man may be ever so good a mechanic, but if he cannot transfer what he knows of the trade to someone else, he cannot be an instructor.

I know of no craft that has been so slow in producing men of that caliber as has the foundry craft. Such men simply have not been developed.

In the absence of such instructors, it seems to me that it is the problem of this craft to develop courses of related instruction in such a way that they can be used by trade instructors other than foundrymen in the class room. Anyone who has ever attempted to draw up a course of instruction will know that it is quite a job to make up a course which will be of value to an instructor who is not a foundryman. To write such a course to be used for foundry apprentices is much harder than it may appear.

It seems to me that foundrymen must take the initiative in the development of proper courses. We cannot rely on the schools to do it for us. I believe the best way to develop this is through the organization of local and state-wide apprenticeship committees. We have them in a number of crafts in Wisconsin, and we think they are a wonderful improvement over the old individual method.

We need leadership in the foundry trades. We need men who will organize committees and lead them and develop their work.

In reading Mr. Brah's paper I was surprised to learn that there still are some foundrymen who must be shown that related class-room instruction is needed. I thought almost everyone agreed that related class-room instruction is valuable.

CHAIRMAN C. J. FREUND: One of the difficulties which stand out in the matter of school instruction, particularly in the early stages of development of an apprentice training program in a plant, is the matter of absence from work while the boy is at school. I imagine that at the present time that does not bother anyone.

What I have in mind is the difficulty which confronts the foreman when a boy who was supposed to make a certain number of molds on a

[2] State Supervisor of Apprenticeship, Industrial Commission of Wisconsin, Madison, Wis.

certain afternoon is taken out of the department on that particular afternoon and sent to school because his school requirement calls for his attendance on that day. I think the solution of this problem is still a more or less recent experience.

F. K. FERGUSON:[4] Of course, as Mr. Freund says, that is no problem at all just now. The boy can go to school almost any time he wants without breaking up the morale of the plant.

In times of great production, however, the problem does exist, but the foreman simply has to plan his work accordingly. He has a definite schedule for school attendance. He knows that each boy goes to school on a particular day (in the afternoon, in East Chicago), so that when he plans his work for that day he counts that boy out for the afternoon.

If the apprentice makes an average of ten molds a day of a certain type, the foreman will hold him responsible for only five molds on his school day, and the others will have to be made up by other men or will have to be scheduled over another period of time.

CHAIRMAN C. J. FREUND: What was the reaction of the foremen in the first place when they were told that the boys had to attend school, and probably that they had to be paid for attending school? What particular arguments did you use on those foremen in order to overcome this difficulty?

I can remember very well, cases where foremen were pleased with the idea of apprentice training, until they were told that apprentice training involved one-half day of school attendance per week for which the boy was to be paid—and, probably, in some cases the pay was to be charged to the foreman's department. That is something foremen always are very sensitive about, because they are charged with the costs in their departments.

F. K. FERGUSON: No particular plans were developed. I think the solution depends upon selling apprenticeship to the foremen. If apprenticeship is sold to the foreman, on the idea that this school training is a part of the boy's training, then the ice will have been broken and the foreman will have been prepared for acceptance of school attendance.

In some cases we have had objection from foremen. I remember several cases where the foreman would be up against it and would say, "Well, I need this boy very badly."

Sometimes we change the boy's school day. For instance, if a rush job comes in that must be out before Wednesday and the boy is scheduled for school attendance on Tuesday, our classes are so arranged that the boy can drop in on the Thursday or Friday class without making any great disturbance in the school.

That is one solution for the problem. Where classes are extremely large, of course another problem would arise, in that there might have to be another sort of shift.

MEMBER: What system is used in paying for the instructor's time?

[4] Vocational Instructor, East Chicago Public Schools, East Chicago, Ind.

Do the individual firms pay according to the number of students they have attending the classes?

S. M. BRAH: Looking at the paper, it will be seen that the data compiled are in two classes. Table 1 includes municipally conducted continuation schools similar to the program Mr. Ferguson is working on, in which a number of plants in the district send the boy to a public school building. From the column headed "School Expenses Paid by," it will be seen that in a number of cases these are paid by the school, in a few cases by the manufacturer, and in other cases by the school districts and manufacturers together.

In Table 2 are the data from individual plant schools, such as those maintained within the plant by the General Electric Co., Westinghouse Electric & Mfg. Co., Bausch & Lomb Optical Co., Brown & Sharpe Mfg. Co., Caterpillar Tractor Co., etc. In some cases, it will be seen, the manufacturer pays all the expense, while in a few isolated cases the manufacturer, the local school board and the state department and federal department of vocational education (under the Smith-Hughes Act), pay the instructor's salary.

H. S. FALK:[5] Regarding the question previously asked, and without inflicting too much Milwaukee data on this group, I should like to explain how the problem of school attendance was solved in some of the Milwaukee plants.

We found it difficult, particularly in the machine shops, to keep large and important tools in operation when the apprentices who operated them attended school. We inaugurated a system whereby some of our older apprentices, perhaps those in their last year of training, would act as "pinch hitters," so to speak, to take care of the absenteeism for school attendance.

We had in our machine shop one or two such boys and the solution for the problem worked out quite nicely. We used these boys to fill up the empty machines every morning and every afternoon. They had no definite assignment for any day, but had to go in and operate any machine where absenteeism was a problem.

That gave us, perhaps, a little surplus man power, apparently; but if a mechanic was absent, one of these young men would step in and take the mechanic's place. Or, if it happened to be an apprentice who was away at school, the other apprentice stepped in and took his place.

This served a double purpose. It kept all of the tools running as they should run—I am speaking now of times other than the present—and also gave those boys a very fine opportunity to get more experience on certain tools, even on tools that may have been partially or entirely omitted from their regular course of instruction.

We believe that this is a solution—perhaps not the only possible solution, but still a feasible one that works out very nicely both for the plant and for the boy, because it broadens his experience considerably.

JOHN H. PLOEHN:[6] In the Tri Cities we have a situation which is a

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[6] Superintendent, French & Hecht, Inc., Davenport, Iowa.

little different from that in most other places, because we are located in two states and have to handle this problem with three school boards on the Illinois side and one school board on the Iowa side of the river.

All this instructional work is being done by the school authorities without any cost to the manufacturers directly. We finally ironed it out with the state vocational funds, the Smith-Hughes Act and the cities. We are getting along very nicely now.

At first we had a little difficulty in selling the idea of the necessity for this school-room instruction, but we explained the economic side of the situation and pointed out that the manufacturers, who are contributing probably a very large percentage of the taxes that go to the school board, are entitled to some consideration. We also pointed out that some of the boys who have to leave school and earn their livelihood are ambitious to better themselves and also are certainly entitled to just as much consideration as are the boys who are more fortunate and continue through high school and college.

We have had some little trouble in the matter of absence for actual school attendance, but to a certain extent we have worked out this problem in our individual plants by taking into account the fact that both the foreman and the boy know when the latter goes to school. Whatever work the boy is doing is so arranged that it can be done by others without holding up the schedule.

Not only have we had boys in the foundry, but we also have had them in the machine shop and erecting shop, and we have had no trouble at all with apprenticeship, in the past few years, even during our peak production periods. Everything now goes along very smoothly.

As Mr. Ferguson says, one's own organization must be sold on apprenticeship from the top down; then the foreman will give the support which such an enterprise needs and should have.

We feel that, because of the class-room work, we are getting a better type of man, either as a molder, foundryman or other type of worker, because he gets a better knowledge of blueprint reading and metallurgy. That has helped us very much.

We had one case of a boy who was just about to graduate from his apprentice course. We had him go on the second shift of an 18-hour day, which started at six in the morning and ran until midnight, a continuous foundry operation. The regular cupola man said he would not want to have that second shift; that he felt sorry for the fellow who had it.

We put this apprentice boy on that second hard shift. He went through for six or eight months in the summer time and we never lost a heat, nor did we bridge over at any one time. That boy handled himself like an old master, and our work went along splendidly.

I talked with this boy one day, and he said to me: "Well, there was some of that work we had in school that I didn't think so much of, but I got enough of it so I wasn't afraid to tackle the job, and it is coming through in fine shape."

In the matter of school work we cooperate closely with the school

authorities and select the material which they should teach. We were more qualified to tell the school authorities what they should teach than they were themselves, so we got off the beaten paths of ordinary text books and assembled material that is practical and fundamentally correct.

It is on a level that the boy can understand. He gets the fundamentals. If he gets them, he can keep on going just as far as he likes.

MEMBER: Mr. Brah said that there is no material available in the form of publications that could be used in instructional work. He also said that the shop teacher should not undertake to write instructional papers. I wonder if a committee such as this one has ever thought of undertaking to write a text book that would suit the different conditions one runs up against in instructional work.

S. M. BRAH: If I said what the gentleman just quoted, I contradicted myself, because I stated that I did not believe the foundry instructor or class-room instructor should attempt to write all the text material. Therefore, I implied that there was suitable material to form the basic class-room text material already developed, and obviously there is.

Referring again to the second part of Table 1, in my paper, it will be seen that one of texts used is "Elementary Foundry Technology," a book gotten out by the National Founders' Association, which is an admirable book and the consensus of opinion of many minds in the foundry industry. I daresay any *one* man would have difficulty in writing a text equal to it.

"Foundry Work," by Wendt, is another book that is in use. Also, there is considerable correspondence school material, and the trade journals as well have a lot of material that is suitable, particularly in their data and reference sheets for instruction. The *Transactions* of the A. F. A., too, have value as instructional material.

I do not want to be quoted as saying, if I did say so before, that there is no suitable material. There is a great deal of suitable material, and I would rather be quoted as saying that there is no need to write text books for each individual case, but rather to use those already available. Then, if any writing is to be done by anyone, let it supplement the fundamentals developed in the particular texts that are now available.

MAX KUNIANSKY:[7] We conduct our own plant school. There is very little I can say that will add to the meeting, because we have been engaged in training apprentices for approximately a year.

In times such as we now are having, when the foundry, pattern shop and machine shop are working anywhere from two to four days a week, we require our apprentices to have five 1½-hour classes a week. I would like to know how some of the other plants handle this matter. We handle it by having the classes whether or not the shop operates, and paying the apprentices for that time.

J. DAVIS:[8] We take care of that situation by letting the boy go to school a half day or attend any of our classes, paying him for the time

[7] Works Manager, Lynchburg Foundry Co., Radford, Va.
[8] Supervisor, Allis Chalmers Mfg. Co., Milwaukee.

he attends. If he must come in for a half day and is not regularly working that week, he gets paid for the school attendance, which is charged to the general charge number at the shop.

We also have shop classes once a week. The boy is free to attend these whether or not he is working, and he gets paid for it if he attends.

CHAIRMAN C. J. FREUND: Do you *require* apprentices to attend school at a time when not actually working in the plant, or do you *permit* it?

J. DAVIS: We only permit it. We do not require it because the boy's required 400 hours of class-room attendance usually are finished before he completes his apprenticeship. The additional education will help him, and probably the little pay he gets for the half day of school also helps him. We do it more as a favor to the boy.

S. M. BRAH: In reply to Mr. Kuniansky's question, in our district the practice has been to permit the boy to come to school whether the shop operates on short time or not at all, and he is paid in a manner similar to the Allis Chalmers plan. He is paid for shop and school attendance.

J. DAVIS: Further, in regard to the selection of text material we think we get the best results by devising our own texts based on what we find in other texts and worked up through cooperation with the school and the foundrymen. In other words, we have made up our own texts, for the most part.

This is done in the West Allis Vocational School. The teachers come over to the shop and we spend much time making up the text which we want the boys to study in the school. We believe we have secured better results in that way.

CHAIRMAN C. J. FREUND: Are those courses taught only to your apprentices, or to all apprentices who attend the school to which your boys go?

J. DAVIS: The courses are not taught to all apprentices in the school, but to a majority of them. Of course, our attendance at the West Allis school is composed primarily of our own molders and pattern makers, and our text is taught to them. Other apprentices going to our school probably do not get the same course.

CHAIRMAN C. J. FREUND: In other words, when the instructor has the students in class, he teaches your boys your own course and teaches the other boys the course that has been worked out without the supplement you add to it. Do you make all these arrangements through your local vocational board or through mere contact with the teacher?

J. DAVIS: Through the supervisor of the school, the director and the teachers. Most of our foundry teaching in this respect is under one teacher. He cooperates very closely with us.

(Further discussion on apprentice training is included with the following paper and begins on page 349.)

Getting a Program of Community Apprenticeship Under Way

By HAROLD S. FALK,* MILWAUKEE.

Abstract

Stressing the importance of local groups developing programs of community apprentice training, this paper details the procedure of starting such a program and continuing it. Attention and hard work, with some one person made responsible for the enterprise, are prime essentials in any such project. For purposes of illustration, a local manufacturing association is here considered as the sponsoring group. The program will begin with presentation of a statement to the association in order to obtain united, organized support, and the points such a statement should contain are outlined. A committee then is appointed to evolve a plan of training, and, once their plan has been accepted, the committee members should first organize apprentice training within their own plants. Details are given as to organization of such shop programs. After months of trial in plants of the committee members, the task of organizing other member plants may be undertaken. Success in doing this depends on the tact, patience, perseverance and knowledge of apprentice training possessed by the committee. Permanent duties of the committee also are outlined, one of their duties being the making of a survey of the actual need of trained mechanics.

1. When the Committee on Apprentice Training asked me to discuss the organization of a district apprentice training program, it is possible that the members had in the back of their minds that I would tell the story of the development of apprenticeship in the industrial district of Milwaukee. However, I hope they did not have that in mind, for at least two good reasons.

2. The first reason is that I am convinced that there has been so much said and written about the Milwaukee plan of

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NOTE: This paper was presented and discussed before the session on apprentice training at the 1931 convention of the American Foundrymen's Association.

apprenticeship that people must be getting tired of it. I should not like to bore you by an account of something with which you all may be familiar.

3. The second reason is that we naturally made a few mistakes, and I should not like to include those mistakes in my recommendations for the organization of a district program, merely because they happen to have been a part of our experience.

4. We did certain things which we should not do again. In recommending a procedure I should certainly not include anything which our experience has shown to be futile; I should recommend nothing which we should do differently if we had to do it again.

Present Practice Must Be Followed

5. We are told that we should practice what we preach. Presumably, we should preach what we practice. But it does not follow that we should preach what we *have* practiced—we may have discovered that our practice was wrong.

6. Accordingly, I shall make no reference to the district apprenticeship plan of Milwaukee or any other manufacturing community, but shall merely give you my idea of how a district program should be organized and developed, based on our experience our mistakes, and such success as we have had.

Plenty of Hard Work Required

7. The first thing to bear in mind in getting a district apprenticeship plan under way is that the project will require attention and work—hard work. Of course, this sounds obvious, but the statement is appropriate.

8. Business men frequently seem to think that after they have met and decided to establish apprentice training, the work will get under way without anybody doing anyhing further about it. But it will not go ahead automatically, no more than will the decision of a board of directors to spend $200,000 in advertising produce proper copy and art work correctly placed in suitable publications.

9. Someone must assume responsibility for the training enterprise and must go to work on it in dead earnest. Someone must

make it his objective or enthusiasm, and push it with all possible energy. It should not be necessary to mention this, but we know from experience that it is necessary.

STATEMENT OF THE SITUATION

10. Every successful apprenticeship undertaking — indeed, every successful undertaking of any kind—is the result of the energy and enthusiasm of certain individuals.

11. Let us assume that a manufacturer's association is thinking about apprenticeship. The first step undoubtedly is the presentation of a formal statement by enthusiastic persons, as individual members of the association, before a meeting of the association. This statement should outline the need for apprentice training in the locality and in the industry, and should recommend and urge the association, as such, officially to undertake the development of apprenticeship.

The Supply of Skilled Mechanics

12. In addition to pointing out other factors which the local situation may warrant, the statement should emphasize the lack of skilled mechanics which exists in the community and from which the members of the association undoubtedly have suffered. Skilled mechanics here are taken to mean highly trained workmen and experts and not mere machine operators, of which there are enough, apparently, in all districts.

13. The report of these enthusiastic members should explain the relative importance of the local mechanical industry and analyze, if possible, the occupations selected by the graduates of the local schools and high schools in order to demonstrate that the mechanical industry is not getting its proper share of desirable young men of the community. Again, the statement should bring to the attention of the association the normal loss in skilled mechanics in an industrial community every year.

Older Mechanics Must Be Replaced

14. Few employers realize that their force of mechanics is constantly growing older and that the oldest are constantly passing out of the industry and must be replaced. The most conservative estimate of this annual loss that has ever been made

places it at five per cent per year. Accordingly, the industrial community must replace no less than five per cent of its skilled mechanics every year by means of some kind of training, and the advantages of organized training, or apprenticeship, over haphazard methods will be obvious.

15. The importance of the human element in manufacturing must not be overlooked. Business people invariably contend that the most important factor in their business consists of the men who work with them and in their plants. At the same time, the human element is quite intangible and difficult to understand. As a result, most business men do not pay to the human element sufficient attention in proportion to accounting, manufacturing processes, purchasing and other activities which have to do exclusively with the material side of business.

The Competitive Element of Training

16. Again, the members of the local association may not fully appreciate the extent to which educational work has been developed in American industry in recent years. A general tendency of this kind is almost invariably in the right direction.

17. Great numbers of business people in different fields are unlikely to go simultaneously wrong. Accordingly, the members of the association may be warned that failure to undertake work of this kind may cause the industries of the district to fall far behind their competitors in other localities in those advantages which are the direct and indirect result of educational activity.

Importance of Community's Population

18. Also, it is unquestionably important for industries in a community that the people who live in the city or district shall be of the highest possible caliber. A population of low characters will injure the industries as well as all other institutions.

19. Therefore, the first report to the association should point out how the industries can play an important part in creating a superior population by providing for the young men of the community adequate opportunity for trade work and for trade training, so that as many as possible of them may become settled in regular occupations rather than become transient, unskilled workmen.

Organized Action Is Essential

20. The most important part of the report will naturally come last, and will consist of a plea for united action on the part of the association rather than spasmodic attempts in the organization of training by one or the other individual employer.

21. Organized effort in this direction is much superior to individual effort, because organized action always is stronger than individual action. If the work is carried on by the association as an organization, all members will ultimately assume their proper share of the training burden and one or the other important manufacturers will not be training mechanics for the entire district.

Good Will of Community Is Necessary

22. Again, an important factor in successful apprentice training is the good will of the community, of the parents, teachers, pastors, social workers, civic organizations and others interested in young men. The undertaking will not succeed without their support.

23. It is doubtful if training by this or that individual plant would inspire so much public confidence that boys would be sent to become apprentices. On the other hand, when an entire industry goes ahead with an organized project of this kind, every one in the community will necessarily take it seriously and will see in the movement an opportunity for great numbers of the best young men of the city. Only in this way can training be provided for a sufficient number of young men to have a favorable effect upon the caliber of the citizenship.

24. Finally, it may be mentioned that manufacturers and employers associate for every other purpose—for research, for legislation and for advertising—and they can profitably promote the training of men as an organization and thereby develop what they themselves admit to be the most important element in business.

THE COMMITTEE

25. The report which the interested members make to the association on the subject of apprentice training in an open meeting will undoubtedly be favorably received. It is unlikely that any member who has not studied the question thoroughly can suc-

cessfully contend against the supporters of the movement who have given the matter considerable thought and attention.

26. The result surely will be the appointment of a committee to take the necessary action for the institution of apprentice training. Also as usually happens, the enthusiasts who presented the report very probably will be appointed to the committee, which is just exactly what they desire, if they have the correct attitude.

27. The committee then will begin work. At first they will leave the members of the association severely alone. There is no need to urge them until there is something to urge, and a mere demand that they train apprentices is not specific enough. The first business of the committee will be to evolve a plan for the district undertaking.

Subject Must Be Studied Thoroughly

28. The initial step in development of such a plan is a thorough study of the subject of apprentice training. During this first period the committee members will need to work very much alone, although they may occasionally compare notes.

29. Each member will accumulate the greatest possible amount of information on the subject. This can be obtained by systematic reading of current and older issues of various publications, with the help of readers' guides, reports and proceedings of associations and societies, special booklets and pamphlets on apprentice training in general or in some specific industry or locality, books on industrial training and reports of federal and state governments.

30. In addition, the members will do well to attend sessions on training during conventions of associations and, when the occasion arises, to interview employers who have been successful in training apprentices as well as the officials of various government, state and local bodies which have to do with apprentice training.

Organization of Data Accumulated

31. After accumulating a set of notes, each member will examine them carefully and discard all which do not have a local application. This done, the committee meets once more and each member in turn presents the data which he has gathered. There

will, of course, be much duplication and many items and suggestions will not be acceptable to all the members.

32. The result of the meeting should be a carefully selected, if disorganized, set of information which all members of the committee consider relevant and important.

33. Thereupon, one or two members of the committee, perhaps the chairman and one other, will work this acceptable material into a coherent plan. If all members of the committee try to work at this task, utter confusion will result; it is much better for one or two members to prepare the plan and submit it at a later committee meeting for criticism and adjustment.

What Apprentice Plan Should Include

34. The plan should include the following:

(1) The central supervisory committee or organization.

(2) Trades in which apprenticeship is to be established.

(3) Classifications of apprenticeship in the various trades.

(4) Work schedules.

(5) Pay schedules.

(6) Complete arrangements for school attendance and development of suitable school instruction.

(7) The source of candidates for apprenticeship.

(8) Age limit, if any.

(9) Form of the contract or indenture.

(10) Method of certification of graduates of the apprentice courses.

(11) Method of hiring apprentices and of discharging them when necessary.

(12) Supervision of apprentice training in the plant.

(13) Credit to be granted for previous work in the trade.

(14) Term or length of the apprenticeship courses, preferably in hours.

(15) Exchange of apprentices between plants in the association.

(16) Other important matters.

Securing Authority for Initial Work

35. When the plan has been adjusted and corrected until it is satisfactory to all committee members, it is presented by the committee before a general meeting of the association, where the committee members will explain and defend their plans if necessary and will make notes of corrections and adjustments which the discussion in the general meeting may require. This will be an easy matter for the committee, whose members will be so much better informed on the subject of apprenticeship than others in attendance at the general meeting.

36. Immediately, if possible, and at a later meeting if corrections are called for, the plan will be accepted by the association and the committee will be directed to proceed with the organization of the work among the members of the association.

APPRENTICESHIP IN PLANTS OF COMMITTEE MEMBERS

37. Not even now may the committee members launch a general campaign for the development of apprentice training in the association. People expect more than argument from those who are behind a movement of the kind—they want actual demonstration; and it is better to give them actual demonstration, because in the long run there is more likelihood of success.

38. The official approval of the association means very little at the start. Urge a man to do something of the kind and he will tell you to try it yourself first; then, if you have made a success, he will also attempt it.

Arousing the Interest for Training

39. Accordingly, the next step of the committee will be to get the work under way in their own plants, and the first thing to do is to excite the interest and enthusiasm of the members of their own shop organizations. This can be most easily accomplished by calling a meeting of foremen and department heads in order to get their advice and suggestions, and by appointing a committee of their number who will assist in building up an apprentice training system which will suit their own requirements and, at the same time, comply with the specifications which the association has chosen.

40. This is a direct application of the fundamental principle of democratic government that people will support an enterprise when they can have a part in its direction. Men who have lived all their lives in a manufacturing atmosphere, who are skilled mechanics themselves and who will give apprentices their actual training and engage them after they have graduated, can be depended upon for much extremely valuable advice.

41. During the meeting of foremen and department heads called for this purpose, it will be well to explain the arguments and decisions which have been reached by the apprenticeship group and the association as a whole. Presumably, these decisions and regulations are the result of careful thought and consideration and will involve nothing intrinsically impractical. Moreover, the authority of the association will win the respect of foremen and department heads.

Working Out a Plan of Training

42. A plan for the training of apprentices in the shop can be worked out easily from the suggestions which the foremen and department heads will make, combined with the recommendations which have been approved by the association.

43. The plan for apprentice training within the plant must include the selection of the trades and courses which are to be provided in the program, schedules for work and pay in compliance with the regulations of the association, an organization which shall be in direct charge of the work, records for the administration of training and definite arrangement for school work in compliance with the local policy whereby related instruction will be given in vocational and public schools, or private classes.

44. When plans are completed, it is time to engage one or two apprentices—no more than that number. Getting apprentice training under way in a plant is a considerable task, and caring for a large number of apprentices also is a considerable task. It is unlikely that both can be handled effectively at the same time.

45. Accordingly, by starting out with one or two apprentices, personal apprentice problems can be kept at a minimum and most of the time and attention devoted to the development of the system. After the system has been running smoothly and

the burden of organization has been reduced, more boys may be taken on and properly cared for.

Selecting the First Apprentices

46. The first apprentices must be very carefully selected, because the entire undertaking depends upon them. If they are successful, the organization will be likely to accept apprenticeship. If they are failures, the movement will be rejected, and it may be years before another trial may be made.

47. Of course, all apprentices must be carefully selected, but particular emphasis must be placed on the high requirements of the first two or three boys in the plant. The institution must be developed very gradually; at no time must a sudden additional burden, either in the number of boys or in specific duties, be placed upon foremen and department heads, as otherwise they might become discouraged.

ORGANIZING MEMBER PLANTS

48. When the training of apprentices has been carried on successfully for many months, or perhaps a year, in the shops of the committee members, and has become a regular department in the operation of those shops, committee members will be ready to go out among the other plants in the district and promote the establishment of apprenticeship by means of a strong argument in the form of a record of achievement.

49. In organizing apprenticeship in the plants of the members of the association, the apprenticeship committee will encounter its greatest difficulty in the natural human tendency to postpone starting anything—inertia, if you wish to call it that, even on the part of those who approve the training of apprentices, rather than any definite opposition. Opposition will be encountered, but will be found less troublesome than inertia.

50. The success of the committee will depend upon thorough knowledge of their subject (which the members will have acquired by this time), on tact, on patience and on perseverance. Too much aggressiveness will only create antagonism. More will be accomplished by a constant, quiet and relentless effort. The committee cannot expect to go ahead too quickly; real progress will be slow progress.

How Committee Should Proceed

51. At the beginning of their work, it will be well for the committee to divide the plants of the association among themselves, so that each member may concentrate on the calls which have been assigned to him. Thereupon, the committee may meet at intervals to discuss difficulties and objections which the members encounter in various shops, and work up answering arguments.

52. Under certain conditions it may be good for several members of the committee to go together to meet some manufacturer who might be influenced by a delegation more easily than by an individual, or whose objections and attitude may require the attention of more than one member of the committee.

53. In preparing their arguments, the committee will do well to study the policy and attitudes of manufacturers as much as they can be known, in order to shape their method of attack.

Force of Example Is Strong

54. The committee should take the greatest possible advantage of the adoption of apprenticeship in such plants as have gone ahead with the movement, because most people are impressed by the fact that any considerable number of people whom they respect are doing a certain thing. As time passes, some employers may establish apprenticeship in their plants for no other reason than that they do not wish to be considered backward or out of line with a prevailing movement.

Advisory Work by the Committee

55. After a member of the association has agreed to install apprentice training, the committee can assist him in getting the work under way by suggesting a procedure very similar to that which has been successful in their own plants. They will give him all necessary information and advice, help him in the selection of a suitable director or supervisor of apprenticeship, (either from among his own employees, or from elsewhere if none of the present employees can undertake the responsibility), and help him in securing desirable candidates for apprentice training—remembering the importance of beginning with a few apprentices very carefully selected, rather than a greater number chosen at random.

PERMANENT DUTIES OF THE COMMITTEE

56. After apprentice training has been fairly well established in the industries of the community, at least to the extent that a majority of the industries have begun the training of apprentices, the committee should undertake some kind of survey to determine the actual needs of the industry for trained mechanics.

57. It has been explained that between five and ten per cent of the total number of skilled mechanics in the industries of the community must be replaced every year by graduates of apprentice training programs. Naturally, the number of apprentices employed will be much more than five to ten per cent of the number of skilled mechanics, because only a small number of the apprentices employed will graduate in any one year.

Calculating Number of Apprentices Needed

58. The number of apprentices who must be employed in the community may be approximately calculated from the proportion of apprentices who actually complete their courses, based upon known experience. Considerable judgment will have to be applied by the committee in determining these various factors according to local requirements.

59. The work of installing apprentice training in plants will continue for many years, both because this or that manufacturer may decline to take part in the movement at the start and may not surrender for a long time, and also because new industries will be built up in the community and must be induced to take their proper place in the program.

60. Again, one or the other plant may be permanently closed, and in order to keep faith with the apprentices employed in it, and with the community, the committee must assume the responsibility of placing these apprentices in other plants, if possible, so that they may complete their training.

Apprentice Training Publicity

61. The apprenticeship committee will maintain interest in the community by the publication of information regarding apprenticeship affairs in the newspapers and by talks before civic organizations, luncheon clubs, boys' clubs, parent-teacher associa-

tions and similar groups. Also, they will make it a point to supply information regarding apprentice training to public employment offices and to private employment agencies maintained by legitimate organizations and societies.

62. Furthermore, the committee will need to study official and standard work and pay schedules at regular intervals, in order to adjust them to the change of the times and keep them up to date. A review of wage and pay schedules should be made at least every three years, although changes may be required much less frequently.

APPLICATION OF TRAINING PRINCIPLES

63. It is the custom to close papers of this kind with the statement that the methods described have been successful in a locality or several localities, but that it is impossible to guarantee their success in other communities because local conditions may prevent their application. I shall be so bold as to assume a different attitude.

64. The points which I have made in the course of this paper have been rather general and for a definite purpose. Because they are sufficiently general, it is safe for me to say that the principles which I have attempted to explain may be successfully applied in any American industrial community, although some adjustment in the details may be required by local conditions. These adjustments need not touch or affect the general principles and general practices; I am sure that they will be successful anywhere.

65. It only remains for the local apprenticeship committee, and the officers of the association (if one exists), to display that energy and initiative which the organization of a pretentious undertaking of the kind will require.

Why Training Is Needed

66. Also, I am grateful for this opportunity to urge all foundrymen who have not already done so to begin apprenticeship training. The foundry industry—even the high production plants—require trained workmen.

67. The industry needs to provide organized experience for those young men who will before long become officials and depart-

ment heads. The foundry industry as well as every other industry is a factor in the life of the community in which it is located, and as such it must play its proper part in the development of the youth of the community.

68. Finally, I know that there is no activity in connection with your industry in which you can engage which will bring to you so much personal pleasure and satisfaction as the training of apprentices.

DISCUSSION

H. S. FALK: The difficulty of bringing forth something new in the way of apprenticeship training loomed up when we were asked to speak here on this subject. It occurred to us that perhaps we might make interesting a subject that is uppermost in our hearts because we have tried to attack the problem of apprenticeship on the basis of a so-called community program or community plan.

I do not think there is anything particularly new in such a plan, but it impressed itself upon those of us who started out with the apprenticeship work in Milwaukee approximately ten years ago, that there were a good many shops in every industrial community who had the desire to take part in a training program but who, because of limited finances, could not carry on training in the same manner as the larger shops. Therefore, we tried to work out a scheme that would take these small shops into consideration and give them an opportunity to take part in the program by contributing to it. Thus they could be free to benefit by the program without feeling as though they were riding along "deadhead" when someone else was paying the bill.

This prompted us in Milwaukee to consider carefully the possibilities of a community program, and finally made us adopt such a plan. There are, as you know, many small plants which are very anxious to be included in this activity.

Our plan in Milwaukee contemplated the use of plant instructors or supervisors, because we realized that the boy, under the ramifications of the present-day business set-up, would be lost in the shuffle unless someone was appointed to look after his interests. In order to include these smaller plants in this participation, this so-called community plan was adopted.

That is the angle we have presented in the speaker's paper, leaving perhaps a few thoughts that we have gained by experience in the use of this scheme. Anyone interested in trying out such a plan in his own

community possibly can benefit by our experiences, and our mistakes, although we have tried conscientiously to leave them out of the paper.

CHAIRMAN C. J. FREUND: It seems to me that if anything has been made clear by Mr. Falk's paper, it is that if a district apprentice training program is to be made a success, it must be undertaken with a considerable amount of enthusiasm and the determination on the part of one or the other individuals—at least at the start—that the project will be made a success in spite of all kinds of opposition and lack of interest.

We all believe that apprentice training in a district can be put over under any conditions, provided there are those who sufficiently realize its importance and are willing to give it the time and the energy that are required.

G. P. SINGER:[1] I happen to be rather deeply involved at the present time in formation of just such a district program in my own home town. I want to say that I believe this paper will be of material benefit to me in this work. We have been working on our program for about a year, and I want to present this paper to our chamber of commerce for their benefit and instruction.

There is one point that Mr. Falk might possibly have stressed a little more, and that is in connection with the personnel and ability of the committee appointed to carry on such a program. I am afraid that, all too frequently, members of an organization representing business will get together for the formulation of such a program without having had any practical experience. They have never taken the time to study its requirements, and they will not take the time to do so.

What is the result? A half-developed scheme is handed over to some concern who, while they may be willing to give apprenticeship a trial, are not overly-enthusiastic about it. Consequently, as there is no leadership coming from the committee, the whole project seems to die a natural death.

This applies not only to a community program but also to the programs of individual plants. An executive may be anxious and willing to have apprentices in his plant, and may set up the program and hand it over to some subordinate to be carried out. I wonder how many executives keep up the personal interest necessary to development of such a program. No matter how good the program may be, it will never succeed if that interest is not present.

A second point to be mentioned in connection with Mr. Falk's paper is the part played in the plan by the community itself. It has always seemed to me that the idea of apprentice training—its purposes—should be two-fold: (1) To produce steady workmen, and (2) to create reliable and thinking citizens.

I am afraid that we are prone to forget the second objective. While we may think we are able to go ahead and do our part, I am convinced that we never will be able to do our share in apprentice training, and do it properly, without careful consideration of the second phase.

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[1] Works Manager, Reading Steel Casting Co., Mount Penn., Reading, Pa.

Right here, I believe, is where the community comes into the plan. We must make the people acquainted with our purposes. As Mr. Falk says, the only way in which that can be done at the start is through civic organizations or the newspapers and publications; but I do not think that is the answer in the long run.

These mediums are all right to begin with, but I believe the finest way of getting apprentice training across to the community is by personal contact between those in charge of the program and the parents in the homes of the boys who are the apprentices. If we make clear to the parents what we are trying to do for their boys, I feel sure that six parents of that type will help the program more than will ten of those who have only a superficial knowledge of what is going on.

A third point I wish to touch upon is the suggestion which Mr. Falk made, that the foremen and department heads be called into consultation before proceeding with an apprentice training program. I have always been inclined to regard the foremen's attitude as one of the greatest obstacles which has to be overcome in installing an apprenticeship program.

We know that the foremen are overburdened with production at times, and they come forward with all manner of objections. They claim that the boy is a dead loss, or that he raises their costs, particularly if they happen to be paid on the bonus system.

Of course, there are some exceptions. However, the executive of the plant may set up his program and probably he can force it through, but unless the heads of the departments are with him whole-heartedly, he cannot make it a success.

P. T. BANCROFT:[2] Several years ago we had Mr. Falk down at Moline to help us start apprenticeship training. We followed his instructions pretty closely, and the plan has worked out very satisfactorily. We have quite a number of apprentices today.

Among the national apprentice contest exhibits our little group of manufacturers have some concrete evidence of what has been going on down in our locality. Our apprentices won first prize in the pattern contest and second prize in the gray iron molding contest.

F. G. STEINEBACH:[3] I wish to compliment the apprentice committee for the splendid work they have been doing during the past few years. Mr. Freund made the statement, at the beginning of his talk, that men are the most important factors in the foundry industry. In our connection with the foundry, we can see that this is absolutely true and that this idea is gaining ground right along. The apprenticeship work is spreading.

Mr. Bancroft mentioned that Mr. Falk went over to the Quad Cities and told them how to start their program. I had the pleasure of listening to Mr. Falk tell the Cleveland group, about a year ago, how to start out on a similar program.

Mr. Falk intimated in his talk that perhaps so much has been said

[2] Foundry Superintendent, John Deere Harvester Works, Rock Island, Ill.
[3] Managing Editor, *The Foundry*, Cleveland.

about Milwaukee that people are becoming tired of it. I do not believe that is true, for we must get our important facts from Milwaukee, from the Quad Cities, from East Chicago and the other leaders. We must take advantage of their pioneering and spread their good work throughout the other cities.

(*Further discussion on apprentice training will be found on pages 327-335, inclusive.*)

The Character of Sand Grains*

By H. Ries† and G. D. Conant,** Ithaca, N. Y.

Abstract

The authors have made a microscopic study of the sieve separates of several hundred sands. The characteristic features of the constitution, shape and surface of the grains are described, and it is pointed out that these may and probably do exert an influence on the different properties of sand, such as permeability, bond strength, flowing quality, sintering absorption, etc. It is also evident that one cannot determine the formation of the deposit from a study of the texture and grain characters alone.

Introduction

1. The sand research work carried on by the American Foundrymen's Association during the past eight years has involved giving considerable attention to the properties of sands and the methods of testing them, but comparatively little thought has been given to the sand grains themselves, except that the fineness test recognizes sands as being composed of grains of varying sizes, and the Committee on Grading has classified the grains as rounded, sub-angular, angular and compound.

2. It is quite apparent, therefore, that the sand grains deserve more study. Thus, it seemed worth while to undertake such an investigation, if for no other reason than that it might bring to our notice characters which must influence the properties of sand as a whole. This we believe our results will indicate. Aside from this, however, there are other problems which will be referred to.

Problems Involved

3. The problems to be discussed in the paper are as follows:

(a) The relation of the texture of the sand to its mode of origin.

* This work was carried on with the aid of a grant from the Heckscher Research Fund at Cornell University.

† Professor of Geology, Cornell University.

** Assistant in Geology, Cornell University.

Note: This paper was presented and discussed before one of the sand control sessions at the 1931 convention of the American Foundrymen's Association.

(b) The characteristics of the sand grains and the relation of these to the method of origin.

(c) The relation of shape, structure, surface characters and mineral composition to the properties of the sand.

Method of Study

4. During the progress of the A. F. A. sand research work, a large number of samples obtained from many different geologic formations were collected by the various state geological surveys and sent in to the Bureau of Standards or to Cornell University for testing.[1] Of the several hundred tested at the latter institution, the separates from the fineness test were saved and have supplied us with a large amount of material for study, which had to be carried out largely with the microscope. The present work, therefore, represents the results of a microscopic examination of over two thousand separates.

5. Each of these was carefully examined as to shape of grains and the relative abundance of the different shaped ones, structure, character of surface, color, etc. A detailed determination of the minerals present was not included.

6. Photographs of a number are given in this paper, the portions caught on the different sieves being shown separately, as this gives a better idea of the nature of the sand than does one picture of all the different sized grains mixed together.

7. The photographs were all taken by reflected light, using a black background. Illumination was provided at first by two bulbs of 100 watts each, placed on either side and a little above the stage of the microscope. Later it was found that better results were obtained by using a 25-watt bulb in place of one of the 100-watt bulbs. The illustrations represent an enlargement of 6.6.

Origin of Sand

8. Sand deposits may be formed in a number of different ways, the important ones being as follows:

(a) *Residual deposits,* resulting from the weathering of rocks, in which process the latter may be broken

[1] TRANSACTIONS, A. F. A. (1925), vol. 32, pt. 2.

up to a number of small fragments or individual mineral grains, or rock fragments.

(b) *Glacial sands* produced by the grinding action of glaciers working over hard rock.

(c) *Volcanic sands,* representing comminuted fragments of lava ejected by volcanoes during explosive eruptions.

(d) *Stream deposits,* consisting of sand transported and dropped by water currents of varying volume, velocity and load. The sand grains may be carried for varying distances and be deposited in the stream channel, on terraces bordering the river, or at its mouth.

(e) *Marine deposits,* which have accumulated on the ocean bottom. In some cases these are sands which have been carried to the sea by streams, and settled in shallow water, where they have shifted back and forth on the bottom and undergone a sort of milling action. In other cases they have been concentrated along beaches by wave action.

(f) *Lake deposits.* These, in point of origin, are similar to marine deposits, although not usually as extensive; and sorting or grinding of the sand, due to currents or wave action, may be less intense. There may be a sorting as one proceeds from the shore line outward, the finer material being carried farther out. (Figs. 13, 14).

(g) *Wind-blown deposits.* Sand grains often may be carried for a variable distance by the wind and heaped up into dunes, such deposits being common along the shores of the ocean or even inland bodies of water. They may also accumulate in arid regions where the soil is sandy.

9. All of these types, except possibly (b) and (c), are used in foundry work.

Re-Sorting

10. The first three types of deposits described above may be regarded as being of primary origin, while the others usually

have been originally derived from the first three by natural processes of rehandling and transportation. Any sand deposit may therefore be removed and re-sorted by water or wind, these processes no doubt in many cases having been repeated a number of times.

11. The so-called primary sand may have certain characteristics impressed upon its grains, which it may be difficult for natural agents that handle it later to obliterate, although the grains may be somewhat modified as to shape and markings. It is, therefore, these original or inherited characters, which are not always in harmony with the type of deposit in which the grains now are found, that may make it useless to attempt to determine the origin of a deposit from the character of the sand grains. Any group of grains may have gone through several different processes of accumulation before coming to its present resting place.

Classification of Sand Deposits

12. Various classifications of sand deposits have been proposed by different writers,[2, 3, 4] and their field characters described in considerable detail, for these larger features may be of diagnostic importance in determining the origin of the deposit, and this, in turn, may throw light on its probable extent and variations. Some, however, have gone even further and have attempted to show that the grains themselves show features of genetic importance, or that the ratios of the different sizes are closely related to the manner of formation of the sand. These two latter features we believe are of little value in this connection, as our illustrations will show.

Relation of Texture to Mode of Origin

13. Much has been written regarding the relation of texture and distribution of grain sizes to origin, so that one might infer there is a more or less clear relation between them. However, after studying the fineness curves of several hundred sands of diverse origin, it seems doubtful whether any such rule can be laid down. The "sorting index" suggested by Udden[5] for distinguishing between water-laid sand and wind-blown sand, does not appear to fit in a number of cases.

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[2] Trowbridge, A. C., *Jour. Geol.*, XXII. p. 420, 1914.
[3] Sherzer, W. H., Geol. Soc. Amer., *Bul.* XXI, p. 625, 1910.
[4] Udden, J. A., Geol. Soc. Amer., *Bul.* XXV, p. 655, 1914.
[5] Udden, J. A., Geol. Soc. Amer., *Bul.* XXV, p. 736, 1914.

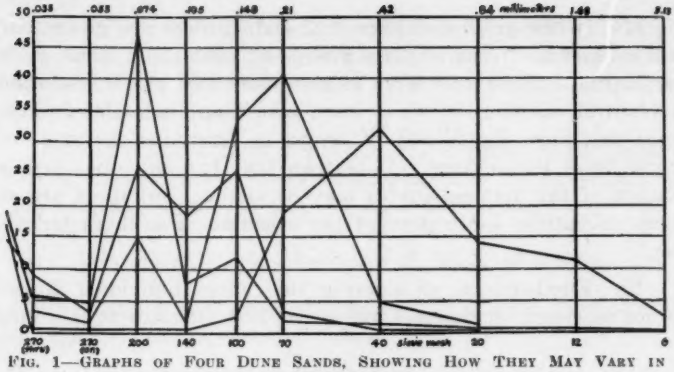

FIG. 1—GRAPHS OF FOUR DUNE SANDS, SHOWING HOW THEY MAY VARY IN THEIR TEXTURE.

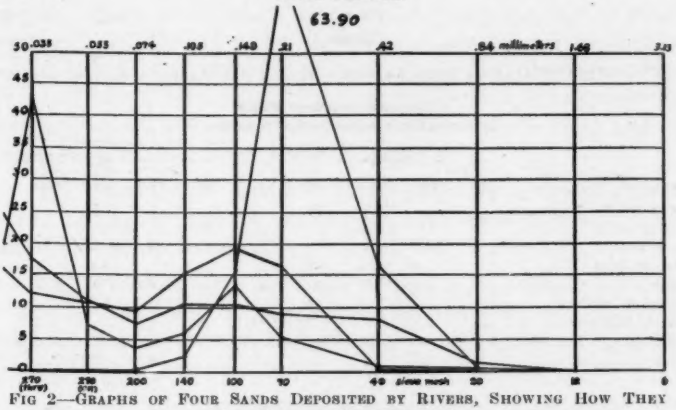

FIG. 2—GRAPHS OF FOUR SANDS DEPOSITED BY RIVERS, SHOWING HOW THEY MAY VARY IN THEIR TEXTURE.

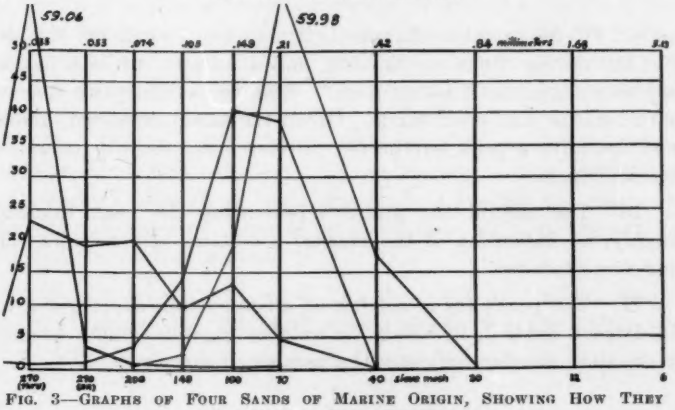

FIG. 3—GRAPHS OF FOUR SANDS OF MARINE ORIGIN, SHOWING HOW THEY MAY VARY IN THEIR TEXTURE.

14. In the graphs of Figs. 1, 2 and 3, there are given four fineness curves of each of three groups of sands; *viz.*, dune, river and marine. These will serve to give some idea of the variation in textural distribution which may take place in each of three types, and show the futility of trying to determine the mode of origin from the texture. It is true that for any one class a number of the fineness curves may be similar, but there are so many exceptions as to prevent the selection of a characteristic one.

15. Furthermore, as showing that these individual curves do not represent single cases, references may be made to the dune

Table 1

SIZES OF GRAINS REPRESENTING PEAKS FOR VARIOUS SANDS

(Figures given in columns headed by sieve numbers, indicate number of samples.)

Sieve No.	20	40	70	100	140	200	Pan	Secondary maxima	Third maxima
River sand	..	..	18	26	..	..	4	7	..
Marine sand	..	11	14	15	..	15	..	35	..
Dune sand	..	2	19	9	..	..	4	5	1
Glacial lake	1	..	4	30	..	..	..	14	1
Albany	..	..	5	..	..	..	3	4	2
Outwash plain	..	..	6	4	..	..	..	..	..
Glacial moraine	..	..	3	3	4	..	1	..	..
Residual	..	4	8	..	..	..	..	8	..
Loess	..	..	2	..	..	..	4	2	..

sands. Of 36 samples examined, 2 showed a peak on No. 40 sieve, 19 on No. 70, 9 on No. 100, and 4 on pan, while 5 had a secondary maximum (double peak). Similar variations are shown by the marine and river sands. Of all the sands examined, about one-third gave a peak on the No. 70 sieve, and slightly more on the No. 100.

16. The size of the grains representing the peak furnish, roughly, an indication of the average conditions under which the sand was deposited.

17. The peaks for a number of sands examined are given in the data of Table 1, in which the number in each column headed by the sieve number indicates the number of samples.

18. While the texture may not necessarily indicate the origin of the sand, it may be characteristic of a given formation, so that sieve tests made of samples taken at different points may show considerable similarity.[6]

19. The Aquia sand formation of Virginia is an example of this, since it shows considerable similarity in its texture at different points over a distance of some fifty miles.

Relation of Grain Characters to Mode of Origin

20. Sand grains originally formed by a given method may show certain characteristic features.

21. Those produced by weathering, if from igneous or metamorphic rocks, would probably be angular and of rough or pitted surface (Fig. 4). If, however, the sand was formed by the disintegration of a sandstone composed of rounded grains of quartz, this rule would not apply. Many streams and beach deposits are not unlike residual ones, because the sand grains have not received sufficient abrasion to round them.

22. Sand grains produced by the grinding action of glaciers might be angular and of varying size, but some river and beach sands are equally so.

23. Volcanic sand, as clearly as any type, might indicate its origin in that many of the grains would be composed chiefly of volcanic glass or pumice, and often have an angular or splintery form.

24. Any process involving transportation in water currents or by wind may cause some remodeling or reshaping of the grains. In this process of moving, the larger grains at least are rubbed or knocked against each other, and this action if continued long enough might cause thorough rounding of the grains, or develop characteristic surfaces on them.

25. In water this contact grinding is counteracted to some extent by the film of water surrounding the grains, which acts as a cushion—the effect being greater, the smaller the grains, so that rounded grains decrease in abundance with an increase in the fineness of the particles.

26. In wind-blown sands the rounding may affect smaller grains than is the case with those transported by water, and

[6] See Trowbridge, A. C., and Mortimore, M. E., *Econ. Geol.*, XX, p. 409, 1925.

Ziegler[7] states that since grains less than 0.75 mm. in diameter cannot be rounded by water, if any of lower diameter show this form it must have been done by wind. Galloway[8] states that if over 50 per cent of the grains are well rounded, the sand is wind blown; but our study of sands of this type shows that there are many which have comparatively few well-rounded grains.

27. Rounding of hard grains, however, is evidently a very slow process, for few marine or river deposits show a large percentage of well-rounded ones. Of 58 river sands examined, only 22 showed rounded grains, and in few of these were they present in any abundance. Of 59 marine sands, only 19 showed rounded grains. In all of these cases there is always the possibility that the round grains show inherited characters, and that they received their shaping during previous periods of handling.

28. Even grains of soft material, when handled by water may show comparatively little rounding (Fig. 21).

29. Figs. 5, 6 and 7 represent specimens of sand from river deposits. The angularity of the grains in the first two is very marked. The third (Fig. 7) shows round grains predominating, but their characters are inherited and were probably developed at an earlier date by another process. In other words, they probably have been derived from some other formation in which the grains were well rounded.

30. Figs. 8, 9 and 10 are classed as marine sands. They are all conspicuous for the angularity of the single grains. It is interesting to compare the Oriskany sand of Pennsylvania (Fig. 10) with two Ottawa, Ill.,[9] sands (Figs. 27 and 28). Both are marine deposits, but the latter are much more rounded than the former.

31. Associated with glacial deposits, there are many stratified sands which have been laid down by waters flowing from the continental glaciers. Others have been deposited in lakes, many of them formed during the Glacial Period. Here again, there is considerable variety of shape. Figs. 11 and 12 represent two grades deposited in the glacial Lake Albany, in both of which the single grains are quite angular.

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[7] *Jour. Geol.*, XIX, p. 645, 1911.

[8] Geol. Soc. Amer., *Bul.* XXXIII, p. 104, 1922.

[9] Lamar, J. E., Ill. Geol. Survey, *Bul. 53*, p. 26, 1928; also Dake, C. L., Univ. Missouri School of Mines and Metallurgy, *Bul. Tech. Ser.*, vol. 6, No. 1, 1921.

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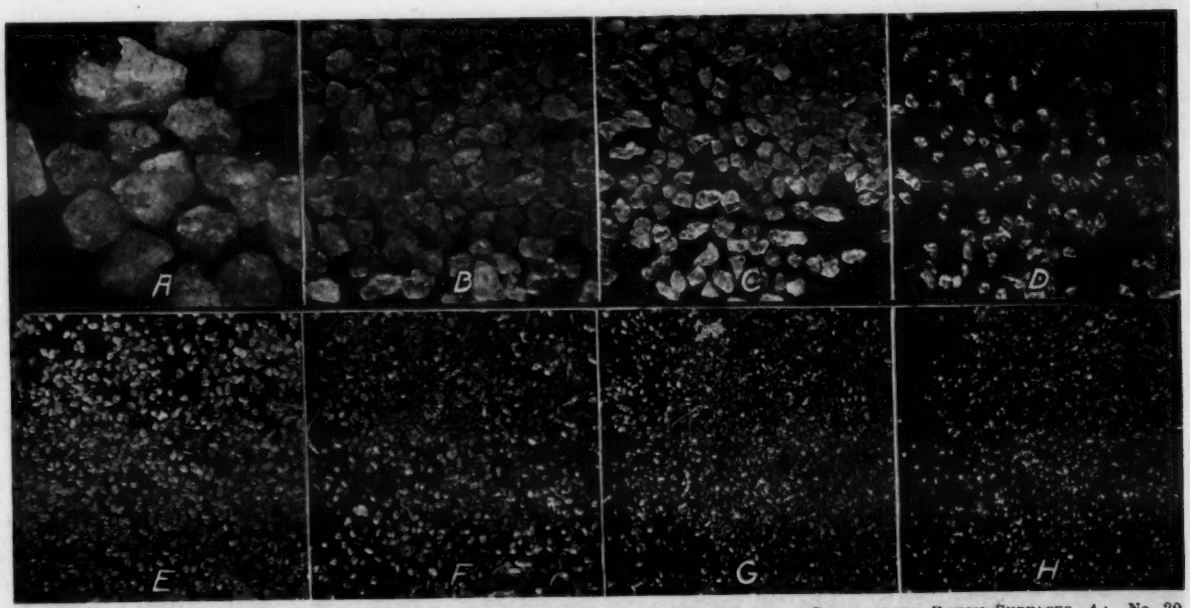

Fig. 4—Separates of a Residual Sand from Utoy Creek, Georgia, Composed of Angular Grains with Rough Surfaces. *A*: No. 20, 1.20%. *B*: No. 40, 8.30%. *C*: No. 70, 27.74%. *D*: No. 100, 14.94%. *E*: No. 140, 5.44%. *F*: No. 200, 2.64% *G*: No. 270, 3.08%. *H*: Pan, 3.74%.

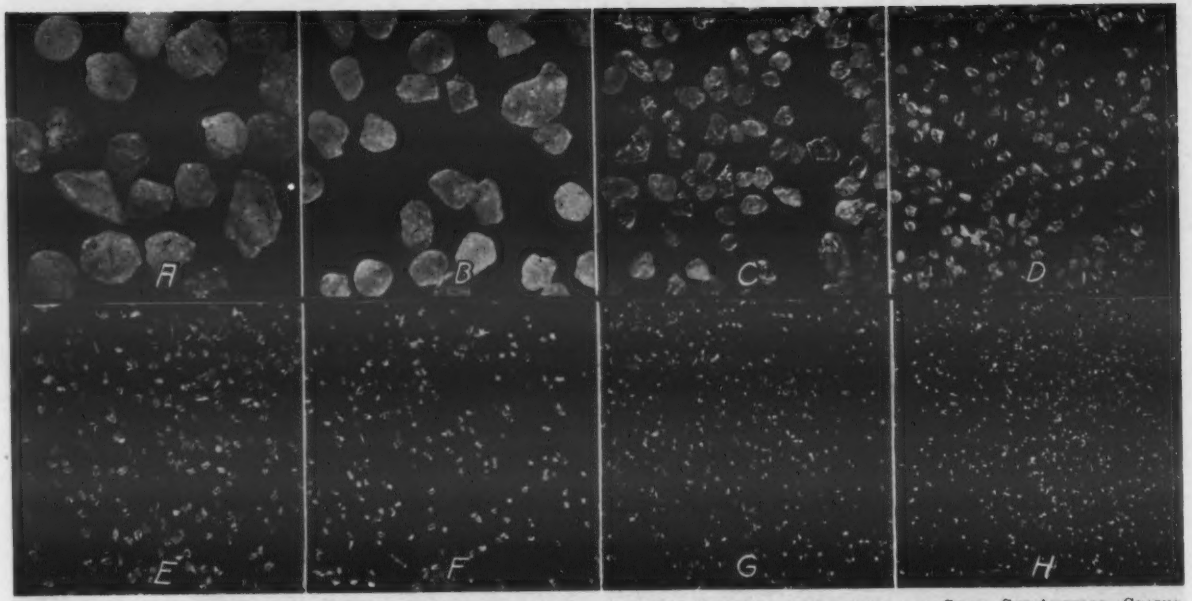

FIG. 5—RIVER SAND (PLEISTOCENE AGE) FROM MILLVILLE, N. J., COMPOSED LARGELY OF ANGULAR AND SOME SUB-ANGULAR GRAINS. WELL-ROUNDED GRAINS SCARCE. *A*: No. 20, 0.46%. *B*: No. 40, 6.30%. *C*: No. 70, 80.88%. *D*: No. 100, 8.40%. *E*: No. 140, 1.94%. *F*: No. 200, 0.58%. *G*: No. 270, 0.44%. *H*: PAN, 0.34%.

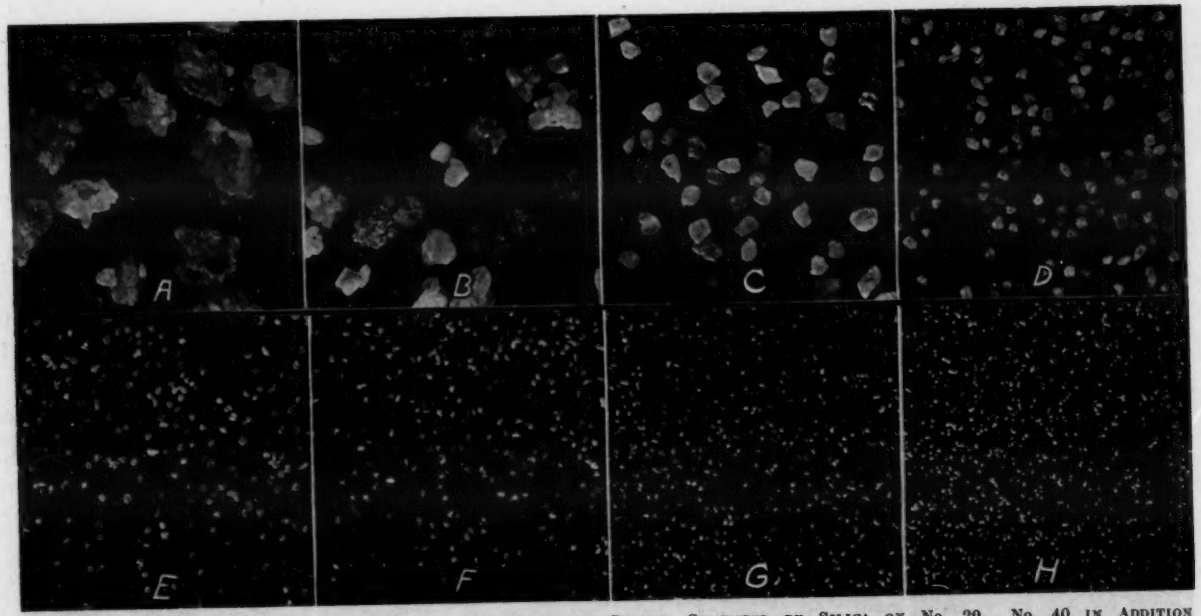

FIG. 6—RIVER TERRACE SAND FROM OIL CITY, PA. ALL COMPOUND GRAINS, CEMENTED BY SILICA ON No. 20. No. 40 IN ADDITION CONTAINS COMPOUND GRAINS (DARK) CEMENTED BY IRON OXIDE. THESE LATTER OCCUR EVEN ON THE 200 MESH. *A*: No. 20, 0.44%. *B*: No. 40, 5.14%. *C*: No. 70, 8.90%. *D*: No. 100, 9.88%. *E*: No. 140, 11.96%. *F*: No. 200, 10.70%. *G*: No. 270, 16.90%. *H*: PAN, 21.10%.

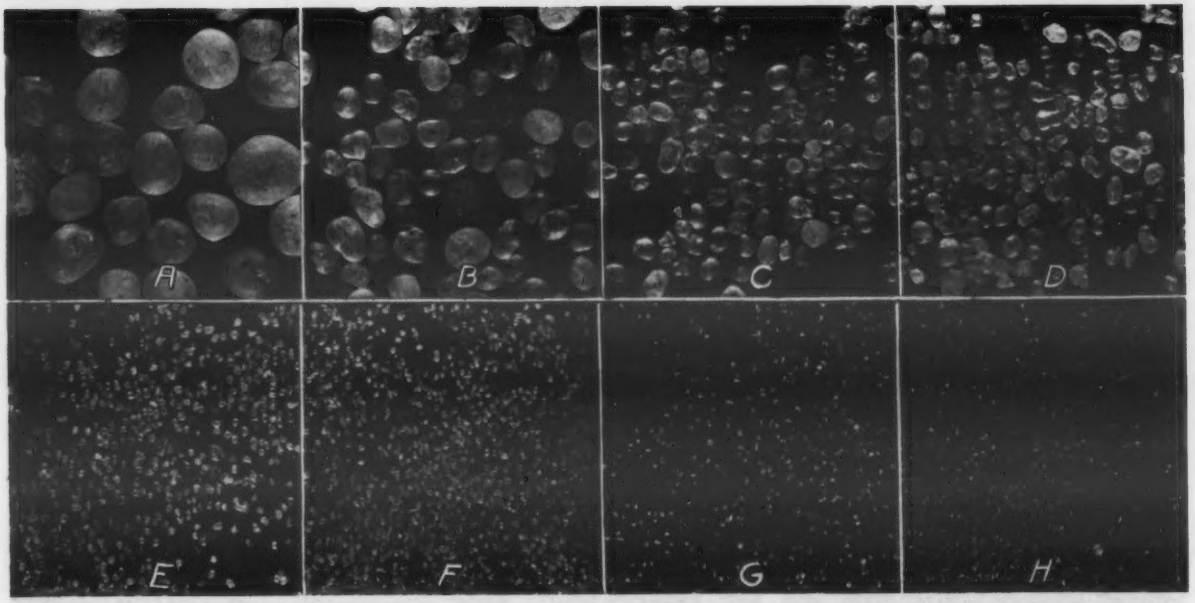

FIG. 7—RIVER SAND FROM MONDOVI, WIS. HIGHLY ROUNDED GRAINS WITH FROSTED SURFACES SHOW INHERITED CHARACTERS AND EVIDENTLY WERE DERIVED FROM DISINTEGRATION OF AN OLDER SANDSTONE FORMATION. *A*: No. 20, 0.50%. *B*: No. 40, 8.64%. *C*: No. 70, 10.18%. *D*: No. 100, 25.46%. *E*: No. 140, 7.36%. *F*: No. 200, 5.12%. *G*: No. 270, 6.00%. *H*: PAN, 19.68%.

FIG. 8.—SAND OF MARINE ORIGIN FROM CARSON, VA. GRAINS ALMOST ENTIRELY ANGULAR. *A*: No. 20, 3.80%. *B*: No. 40, 15.70%. *C*: No. 70, 20.04%: *D*: No. 100, 8.20%. *E*: No. 140, 2.64%. *F*: No. 200, 8.98%. *G*: No. 270, 1.88%. *H*: PAN, 8.80%.

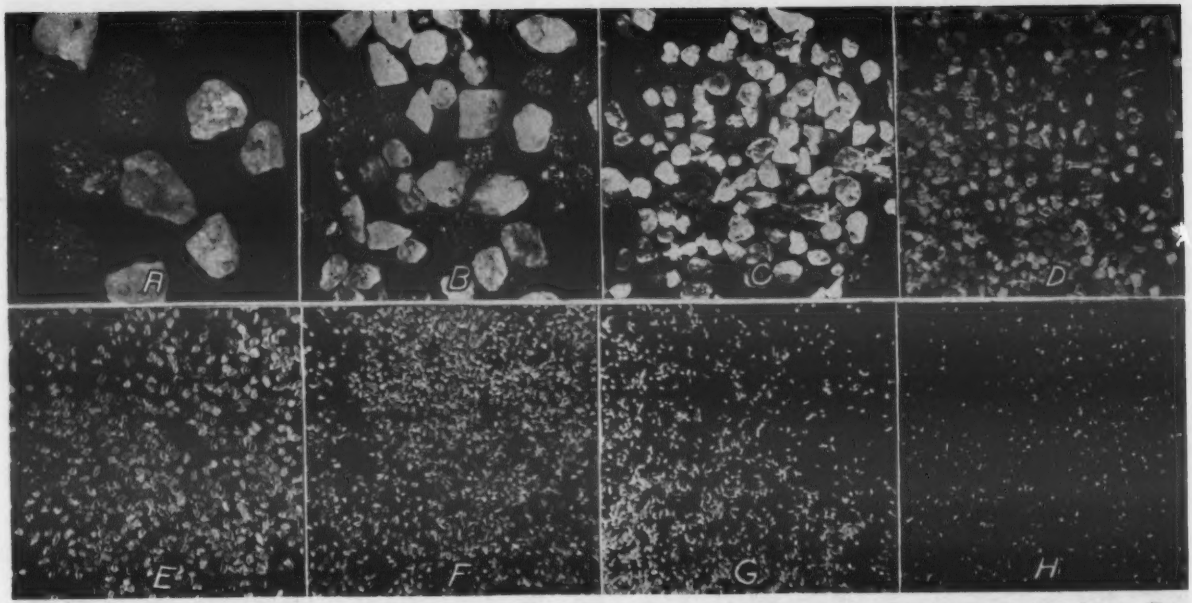

FIG. 9—SAND OF MARINE ORIGIN FROM FREDERICKSBURG, VA. NOTE ABUNDANCE OF COMPOUND GRAINS CEMENTED BY IRON OXIDE. THE SINGLE GRAINS ARE MOSTLY ANGULAR. *A*: No. 20, 1.50%. *B*: No. 40, 1.78%. *C*: No. 70, 4.08%. *D*: No. 100, 4.40%. *E*: No. 140, 3.64%. *F*: No. 200, 56.80%. *G*: No. 270, 5.14%. *H*: PAN, 7.98%.

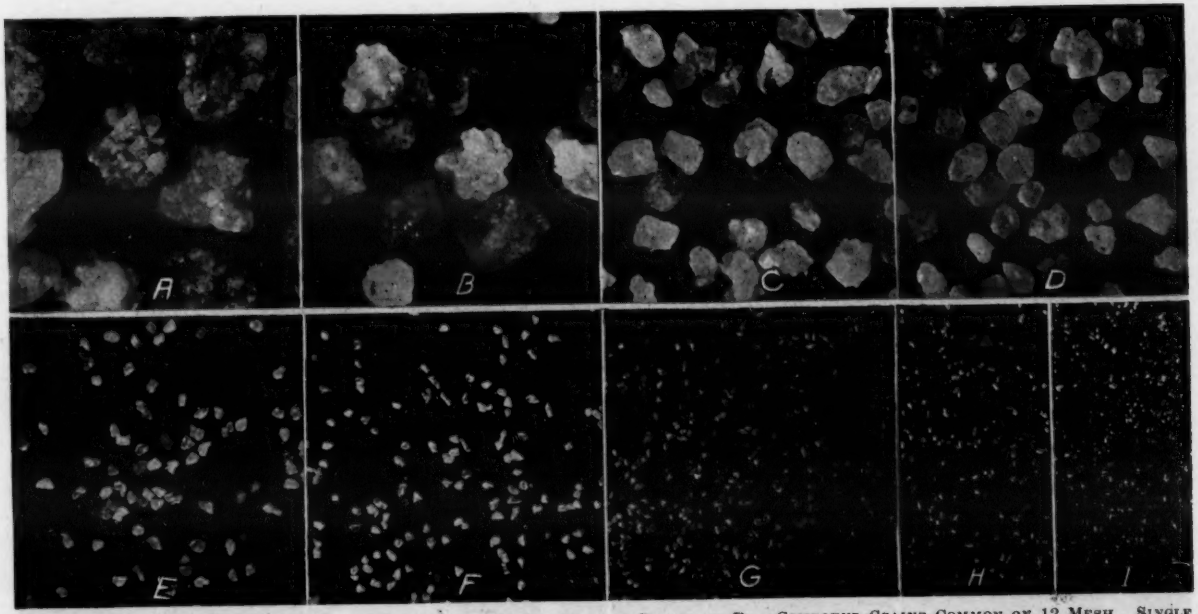

FIG. 10—WHITE SAND (ORISKANY FORMATION) OF MARINE ORIGIN FROM RIDGEWAY, PA. COMPOUND GRAINS COMMON ON 12 MESH. SINGLE GRAINS MOSTLY ANGULAR. SOME SECONDARY GROWTH OF SILICA. *A*: No. 12, 0.94%. *B*: No. 20, 4.88%. *C*: No. 40, 23.44%. *D*: No. 70 54.18%. *E*: No. 100, 4.90%. *F*: No. 140, 2.28%. *G*: No. 200, 1.00%. *H*: No. 270, 1.00%. *I*: PAN, 2.14%.

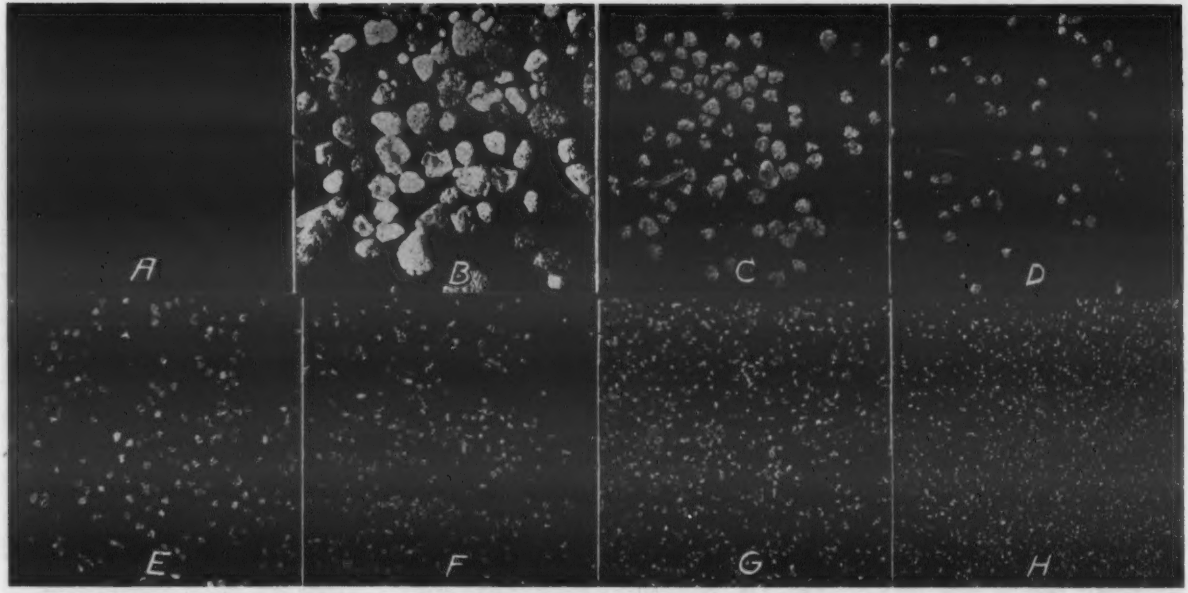

FIG. 11—ALBANY, N. Y., SAND, GRADE NO. 00, DEPOSITED IN A GLACIAL LAKE. NOTE ABUNDANCE OF COMPOUND GRAINS, GRANULES CEMENTED BY IRON OXIDE. THEY OCCUR EVEN ON NO. 200 SIEVE. *A*: No. 40, 0.10%. *B*: No. 70, 0.40%. *C*: No. 100, 1.10%. *D*: No. 140, 3.74%. *E*: No. 200, 11.96%. *F*: No. 270, 17.20%. *G*: PAN, 45.96%.

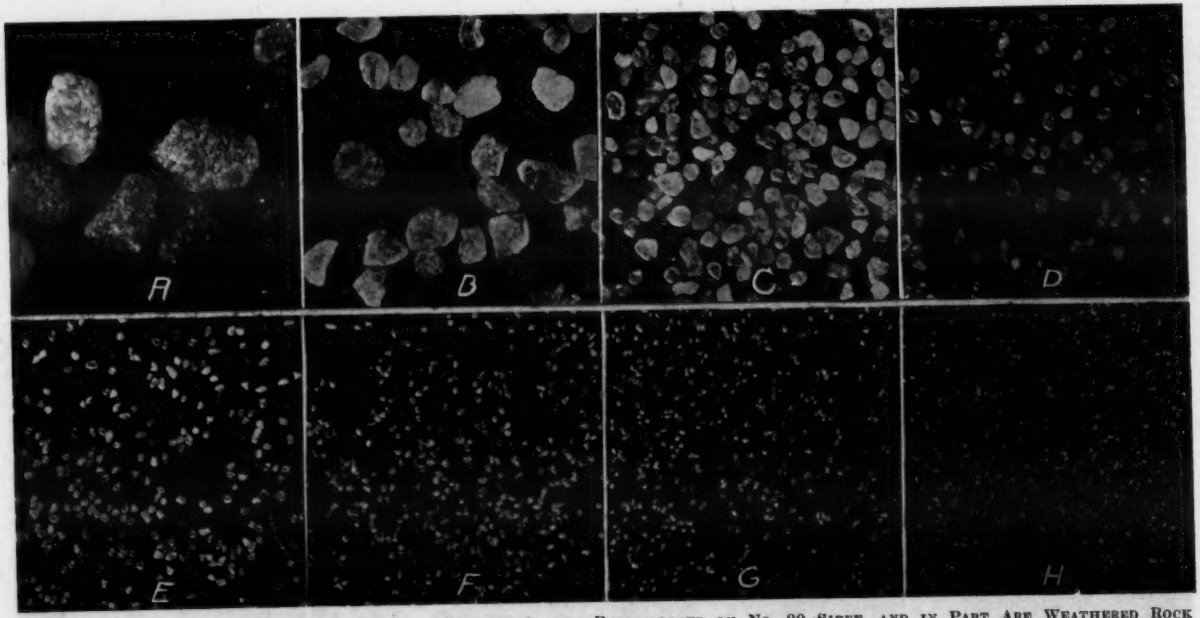

FIG. 12—ALBANY, N. Y., SAND, GRADE NO. 3. COMPOUND GRAINS PREDOMINATE ON NO. 20 SIEVE, AND IN PART ARE WEATHERED ROCK FRAGMENTS. SINGLE GRAINS ARE MOSTLY ANGULAR. PRACTICALLY NO COMPOUND GRAINS BELOW NO. 100 SIEVE. *A*: No. 20, 0.76%. *B*: No. 40, 17.08%. *C*: No. 70, 30.80%. *D*: No. 100, 5.74%. *E*: No. 140, 4.10%. *F*: No. 200, 6.24%. *G*: No. 270, 5.56%. *H*: PAN, 11.68%.

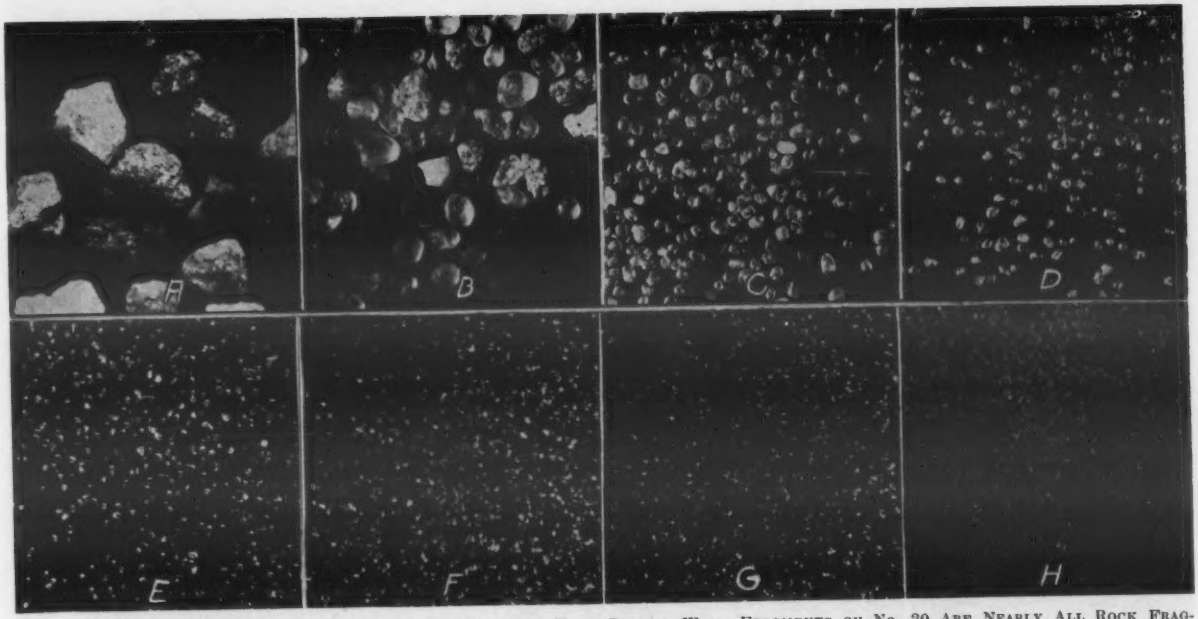

FIG. 13—SAND FROM BEACH LINE OF ANCIENT GLACIAL LAKE NEAR BERLIN, WIS. FRAGMENTS ON NO. 20 ARE NEARLY ALL ROCK FRAGMENTS. COMPOUND GRAINS ARE RARE BELOW NO. 70 SIEVE. SINGLE GRAINS ROUND AND SUB-ANGULAR, WITH ANGULAR ONES INCREASING ON FINER SIEVES. *A*: No. 20, 0.08%. *B*: No. 40, 0.56%. *C*: No. 70, 8.60%. *D*: No. 100, 11.98%. *E*: No. 140, 9.72%. *F*: No. 200, 9.94%. *G*: No. 270, 12.14%. *H*: PAN, 23.58%.

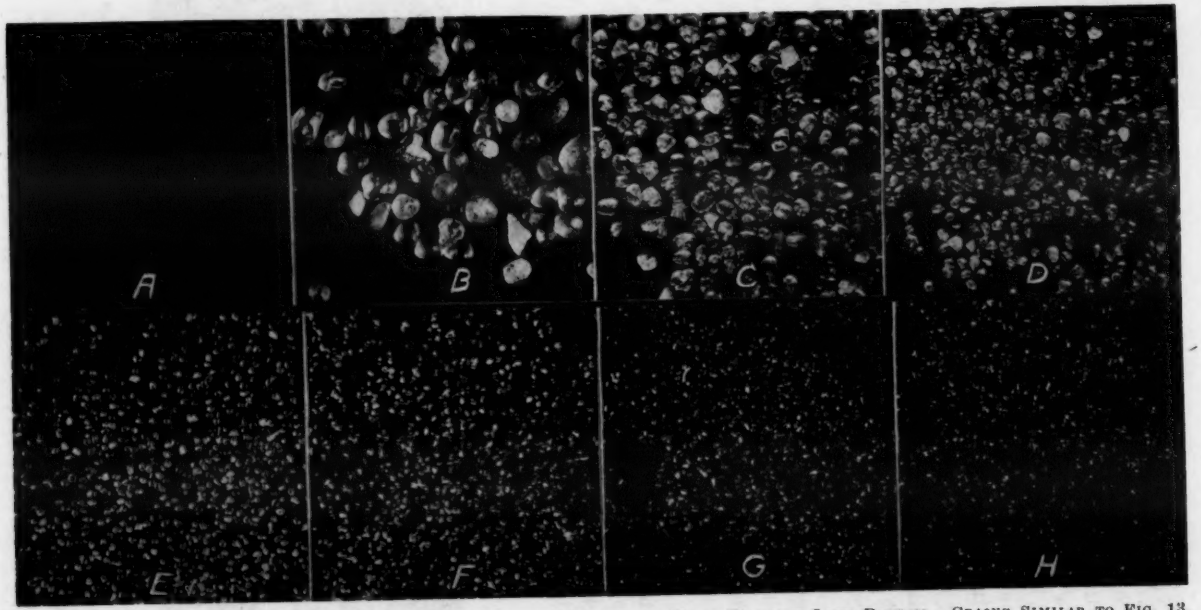

FIG. 14—SAND FROM SAME LAKE AS IN FIG. 13, BUT SAMPLE FROM PIT IN WHAT WAS THE LAKE BOTTOM. GRAINS SIMILAR TO FIG. 13, BUT COARSE SIZES LACKING AND COMPOUND ONES RARE. *A*: No. 40, 0.58%. *B*: No. 70, 8.20%. *C*: No. 100, 53.92%. *D*: No. 140, 21.48%. *E*: No. 200, 9.40%. *F*: No. 270, 4.60%. *G*: PAN, 0.70%.

32. Contrasted with these are two from a glacial lake near Berlin, Wis. (Figs. 13 and 14), which exhibit more rounded grains. Fig. 13 is from near the shore line of the lake, while the sand shown in Fig. 14 was deposited farther out from the shore and shows a finer texture, although it contains as many rounded single grains, but their properties are probably inherited and the grains have no doubt been obtained largely from the Eau Claire sandstone, in which they are already rounded.

33. Dune sands are thought by many to be composed of rounded grains, although the amount of rounding will depend in part on the distance they have been transported, the size and hardness of the mineral grains, and their primary shape; but of all the samples examined, very few showed well-rounded particles.

34. Fig. 15 exhibits an unsieved sand of dune origin from Cape May, N. J. In this the grains are more rounded than usual and, incidentally, show rather close sizing.

35. Fig. 16 shows a gypsum sand from New Mexico. It would be thought that the softness of this mineral would permit it to be easily rounded, yet few of the grains are well worn, although in this case some of the angularity may be due to the grains breaking off along the cleavage planes of the gypsum.

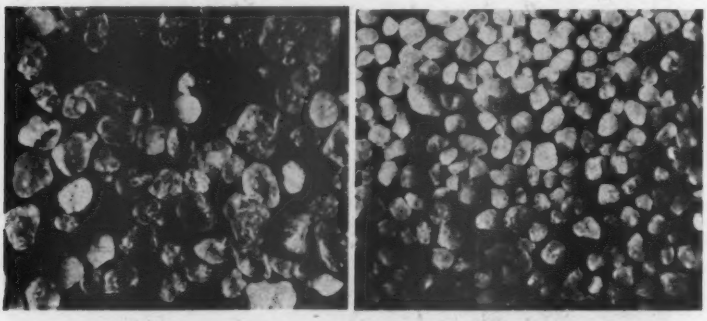

FIG. 15 (LEFT)—UNSIEVED SAMPLE OF DUNE SAND FROM CAPE MAY, N. J. GRAINS SHOW PITTED SURFACES. THIS SAND IS WELL SORTED, AND GRAINS SHOW MORE ROUNDING THAN THOSE OF MANY OTHER DUNE DEPOSITS.

FIG. 16 (RIGHT)—UNSIEVED SAMPLE OF DUNE SAND COMPOSED OF GYPSUM. GRAINS SHOW PITTED SURFACES. THIS SAND IS WELL SORTED, AND GRAINS ARE MODERATELY ROUNDED.

36. In the Michigan core sand, which is of dune character (Fig. 17), well-rounded grains are noticeable only on the No. 30 sieve, and only about 15 per cent of these show this feature. Of greater angularity are the dune sands of the Cape Henry district, Virginia (Fig. 18), used for core work. The sample here illustrated was collected about one-quarter mile back from the beach. Both of these consist largely of quartz grains.

37. In contrast with these are some of the dune sands from California (Fig. 19), which carry from 20 to 30 per cent of dark minerals. The grain shapes are intermediate between the angular Virginia ones and those of Michigan.

38. Fig. 20 shows an Arizona dune sand composed largely of fragments of volcanic material, while Fig. 21 shows a calcareous dune sand from Hawaii, of no use in foundry work. In spite of the soft character of the material, rounded grains are noticeable only in the coarser sizes, and what rounding there is may be in part due to solution.

CHARACTER OF SAND GRAINS

Shape of Grains.

39. Sand grains can be divided into single and compound and the former may be further subdivided into round, sub-angular and angular.

Compound Grains.

40. These may be found in practically all kinds of sand (Figs. 6, 9, 10 and 12), but on the whole they are comparatively rare. They may consist of small grains which have become cemented by iron oxide (Figs. 9 and 12), by silica (Figs. 6, 10 and 23), or by lime carbonate (Fig. 22), after the deposition of the sand, or they may represent fragments of granular rock such as sandstone (Fig. 24).

41. While some compound grains distintegrate readily in water, many are quite permanent and resist disintegration in a stirrer, where the action during agitation is somewhat violent, or even when the rock is put through a crusher (Figs. 25, 26). In making a fineness test of the sand, therefore, they should not be crushed up.

42. Contrary to expectation, compound grains are not always confined to the larger sieve sizes, but in some cases may be found

on all sieves down to the No. 100 (Figs. 9 and 11), although this is perhaps exceptional. It is not uncommon to find them on the No. 40 and No. 70 sieves.

43. In Fig. 24 there is shown a sand which contains an abnormally large percentage of porous compound grains, even down to the 70 mesh. Fig. 6 shows two kinds of compound grains. Those on the 20 mesh are mostly quartz, cemented by silica, while those on the No. 50 are in part of this type and in part very small grains cemented by iron oxide, as shown by their dark color.

44. A curious type of compound grain is that shown in Fig. 22, which consists of tubes of fine sand, cemented by lime carbonate. These are from the Loess. Similar ones have been noted from a sand in northern Illinois.[10]

45. Compound grains appear to be absent or rare in dune sands.

Simple Grains.

46. These, as already stated, may be divided into round, sub-angular and angular. Some writers have made another type called sub-rounded, but to the authors this hardly seems necessary. Transitional forms between the three types always occur.

47. The rounding of grains obviously is due to the abrading of one grain by another, and in order to develop well-rounded grains of quartz it is quite evident that a considerable amount of rubbing is necessary. Cleavage planes in mineral or rock fragments might interfere with rounding under any conditions.

48. In spite of the fact that we often speak of rounded sand grains, well-rounded ones are quite rare. Moreover, this good rounding rarely extends to the smaller sizes; in fact, they do not as a rule seem to extend below the No. 70 sieve, and few above the No. 40 sieve. In some sands the well-rounded grains do not seem to occur in the coarsest sizes which are present in abundance, but may be found in the sizes next to these.

49. Since, as remarked above, rounding depends on the amount of rubbing which a grain has undergone, this may be due either to long transportation or frequent shifting back and forth in water, and to their size. Small ones carried in water are separated by a water film, and hence wear little. In sand dunes, well-

[10] Ries, H., and Gallup, H. L., "Molding Sands of Wisconsin;" Wis. Geol. and Nat. Hist. Survey, *Bul.* XV, 1906.

(*Text continued on page 384*)

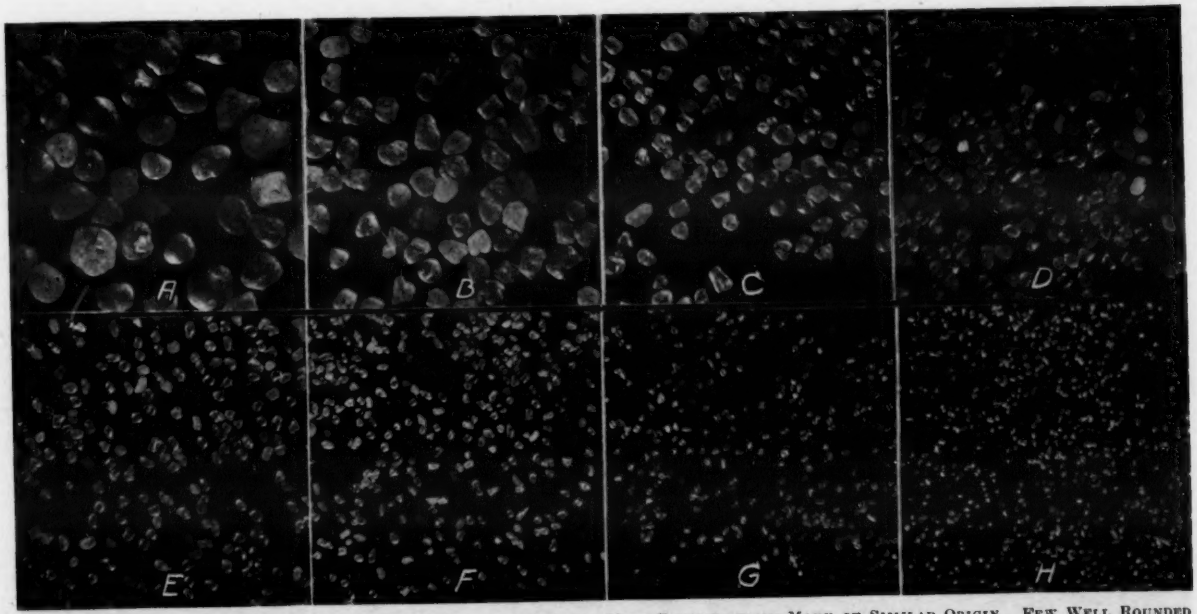

Fig. 17—Dune Sand from Michigan, Used for Cores. Grains More Rounded than Many of Similar Origin. Few Well Rounded Below 70 Mesh, and Angular Ones Increase with Fineness. *A*: No. 30, 0.5%. *B*: No. 40, 6.14%. *C*: No. 50, 37.10%. *D*: No. 70, 44.90%. *E*: No. 100, 10.50%. *F*: No. 140, 0.20%. *G*: No. 200, 0.04%. *H*: No. 270, Trace.

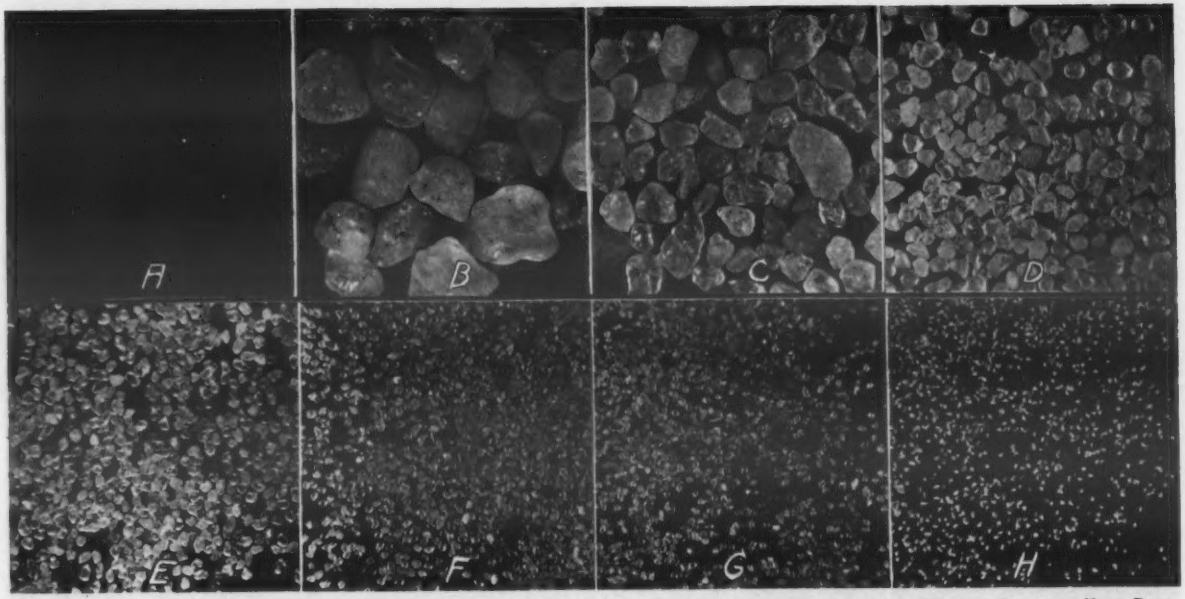

FIG. 18—DUNE SAND FROM CAPE HENRY, VIRGINIA. GRAINS ALMOST ENTIRELY SUB-ANGULAR OR ANGULAR. FROSTED SURFACES VERY RARE. *A*: No. 20, 0.52%. *B*: No. 40, 11.22%. *C*: No. 70, 61.77%. *D*: No. 100, 21.00%. *E*: No. 140, 2.35%. *F*: No. 200, 259%. *G*: No. 270, 0.09%.

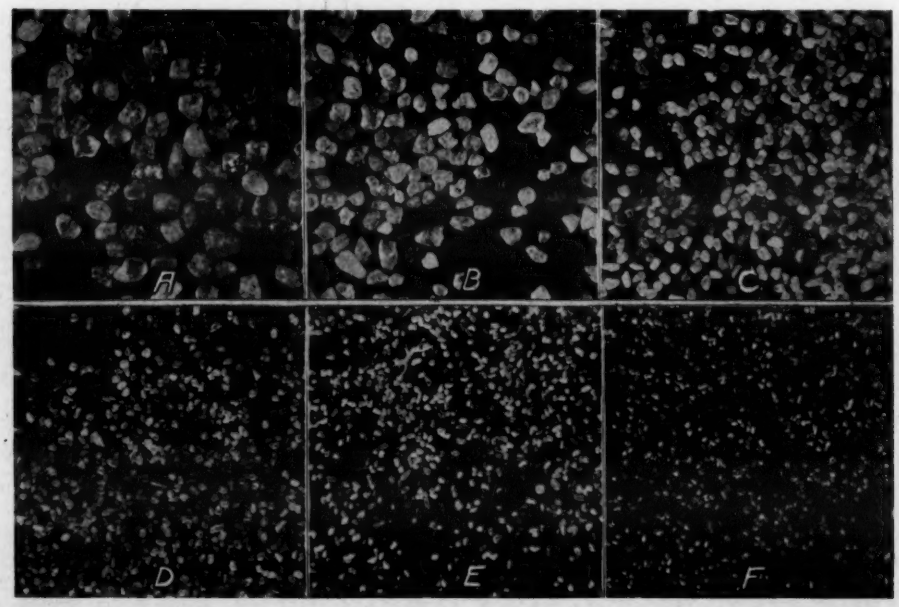

FIG. 19—SAND FROM LEE SIDE OF DUNE ON SAN FRANCISCO BAY, CALIFORNIA. GRAINS SUB-ANGULAR TO ANGULAR. INTERESTING BECAUSE OF LARGE NUMBER OF DARK MINERAL GRAINS IN ALL SIZES, INCREASING ON SMALLER SIEVES. THESE MIGHT REDUCE SINTERING POINTS. *A*: No. 40, 3.46%. *B*: No. 70, 73.54%. *C*: No. 100, 20.64%. *D*: No. 140, 2.14%. *E*: No. 200, 6.34%. *F*: No. 270, 0.66%.

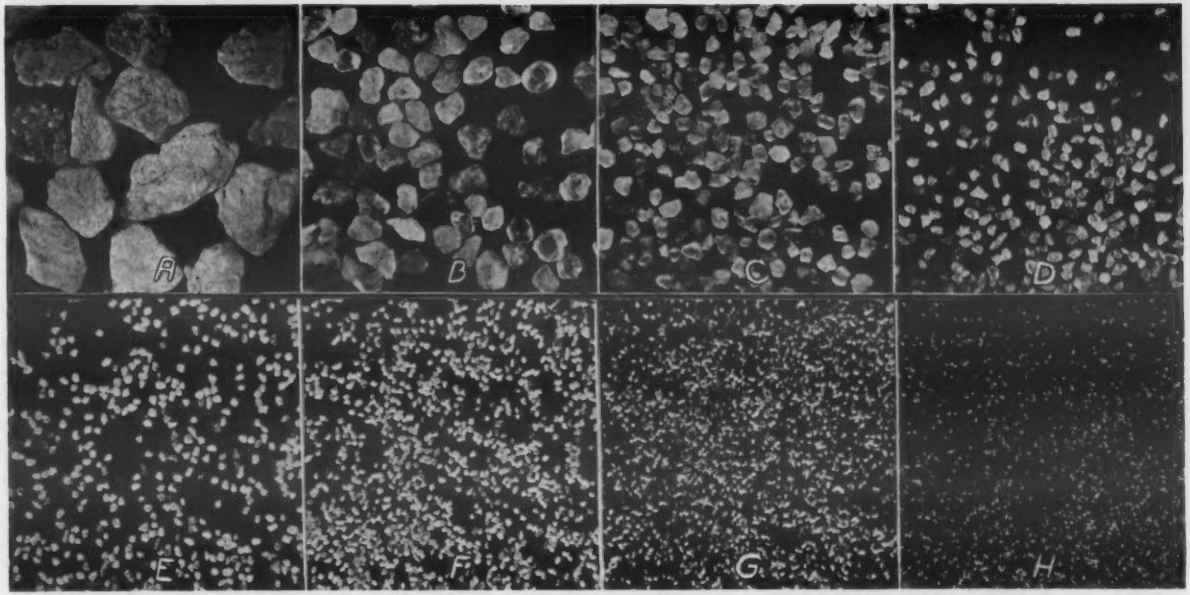

FIG. 20—DUNE SAND FROM DESERT NEAR GRAND CANYON, ARIZONA, COMPOSED LARGELY OF FRAGMENTS OF VOLCANIC MATERIAL. THE 20 MESH ARE PUMICE FRAGMENTS. GRAINS ARE SUB-ANGULAR TO ANGULAR, LATTER INCREASING IN SMALLER SIZES. VERY FEW ROUND GRAINS. *A*: No. 20, 0.28%. *B*: No. 40, 11.96%. *C*: No. 70, 40.72%. *D*: No. 100, 22.44%. *E*: No. 140, 11.76%. *F*: No. 200, 7.14%. *G*: No. 270, 3.76%. *H*: PAN, 1.60%.

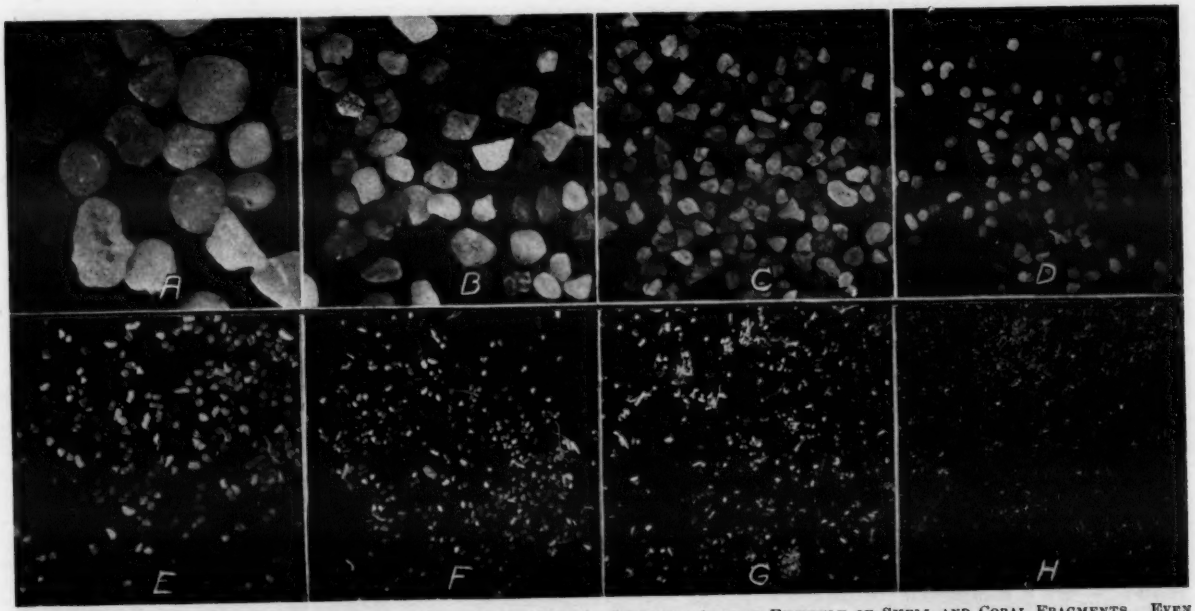

FIG. 21—CALCAREOUS DUNE SAND (BARKING) FROM KAUAI, HAWAII, COMPOSED ALMOST ENTIRELY OF SHELL AND CORAL FRAGMENTS. EVEN THOUGH SOFT, HARDLY ANY WELL-ROUNDED GRAINS EXCEPT ON NO. 20 SIEVE. *A*: No. 20, 1.20%. *B*: No. 40, 53.0%. *C*: No. 70, 44.3%. *D*: No. 100, 2.1%. *E*: No. 140, 0.3%. *F*: No. 200, 0.1%. *G*: No. 270, 0.1%. *H*: PAN, 0.5%.

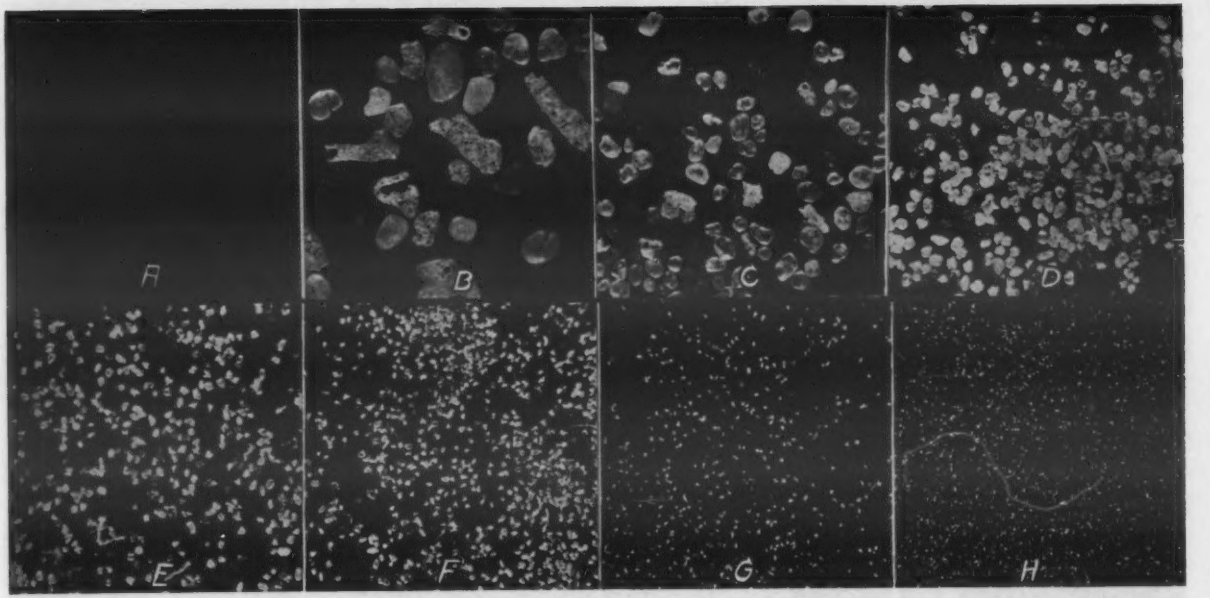

FIG. 22—SAMPLE OF LOESS FROM FLOYD STATION, IOWA. NOTE TUBE-SHAPED COMPOUND GRAINS ON NO. 40 SIEVE. THIS IS A FINE-GRAINED SAND WHICH CARRIES MUCH PAN MATERIAL AND LITTLE CLAY. *A*: No. 40, 0.78%. *B*: No. 70, 4.24%. *C*: No. 100, 1.80%. *D*: No. 140, 1.48%. *E*: No. 200, 1.72%. *F*: No. 270, 11.34%. *G*: PAN, 54.38%.

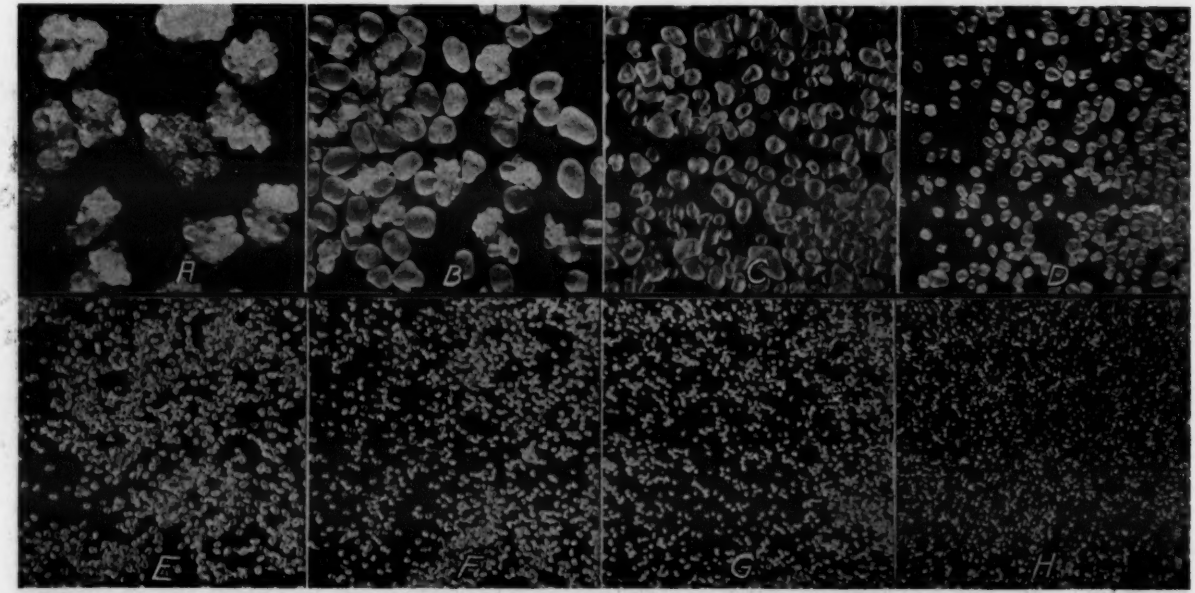

FIG. 23—CRUSHED SAMPLE OF ST. PETERS SANDSTONE FROM RIPON, WIS. COMPOUND GRAINS CEMENTED BY SILICA COMMON ON TWO COARSER SIEVES. ROUNDED GRAINS ABUNDANT DOWN TO NO. 100 SIEVE. SMALLER SIZES ANGULAR OR SUB-ANGULAR, BUT RESEMBLE LARGER SIZED GRAINS IN FORM. *A*: No. 20, 0.66%. *B*: No. 40, 10.02%. *C*: No. 70, 41.52%. *D*: No. 100, 37.08%. *E*: No. 140, 6.26%. *F*: No. 200, 1.38%. *G*: No. 270, 0.70%. *H*: PAN, 0.46%.

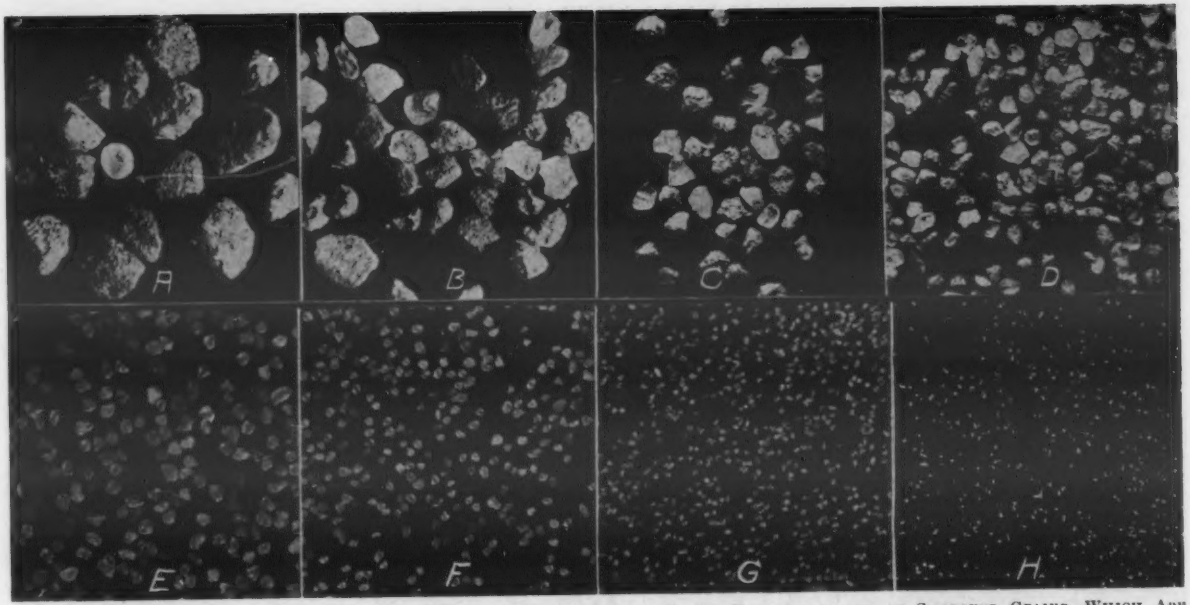

FIG. 24—WATER-DEPOSITED SAND FROM GLACIAL DEPOSIT NEAR HUMASTON, N. Y. NOTE ABUNDANCE OF COMPOUND GRAINS, WHICH ARE PROMINENT DOWN TO NO. 70 SIEVE. MANY ARE PIECES OF RED POROUS SANDSTONE. *A*: No. 20, 0.10%. *B*: No. 30, 0.44%. *C*: No. 40, 1.16%. *D*: No. 50, 6.10%. *E*: No. 70, 22.38%. *F*: No. 100, 38.44%. *G*: No. 200, 8.12%. *H*: PAN, 4.62%.

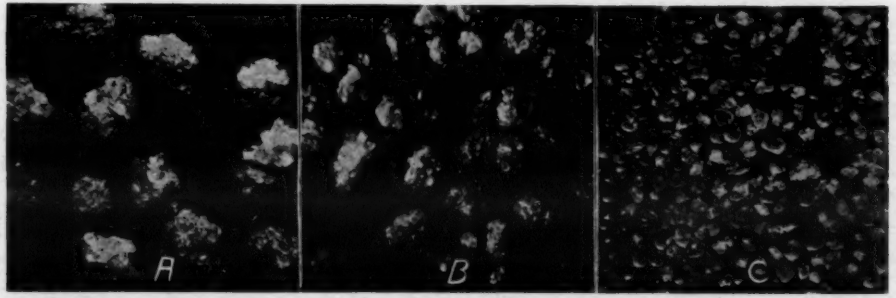

FIG. 25—No. 1 SILICA SAND FROM OHIO, CRUSHED, GROUND AND WASHED. COMPOUND GRAINS VERY ABUNDANT ON No. 40 SIEVE, FAIRLY NUMEROUS ON No. 70. COMPARE WITH FIG. 26. *A*: No. 20, 1.12%. *B*: No. 40, 3.00%. *C*: No. 70, 42.32%.

FIG. 26—No. 1 SILICA SAND FROM OHIO, CRUSHED, GROUND AND WASHED. COMPOUND GRAINS RARE BELOW 20 SIEVE, AND, CEMENTED BY SILICA, HAVE RESISTED CRUSHING FAIRLY WELL. COMPARE WITH FIG. 25. *A*: No. 20, 0.42%. *B*: No. 40, 40.68%. *C*: No. 70, 55.88%.

rounded grains may extend to finer sizes than in sands deposited by water, but few were found on sieves smaller than the No. 140, and most of them were on the No. 40 sieves.

50. We may expect variations, of course, depending on the distance which the sand has traveled. The dune sand at Daytona Beach, Florida, for example, consists of clear, sharp quartz grains. That from one of the Michigan City dunes (Fig. 17) is much more rounded. However, of all the samples of dune sand which were examined, few showed well-rounded grains, even in the larger sizes.

51. So far as the authors' observations go, some of the most beautifully rounded sands are those of the Ottawa, Ill., district (Figs. 27 and 28), but thorough rounding does not extend to the smaller sands. Sands from the same formation are worked in Missouri and Wisconsin and exhibit similar characters.

52. Sub-angular grains do not, as a rule, seem to occur in any great quantity below the No. 140 sieve, but they may extend up to the coarser sieves. Dune sands show a number on the No. 140 sieve.

53. Angular grains seem to predominate on the smaller sieves in all classes of sand; indeed, they become more numerous, as a rule, as the sand increases in fineness. In some cases, however, they predominate even in the coarser sizes (Figs. 4, 5, 8), but this is not confined to sand of any one mode of origin.

Surface of Grains.

54. The surface of simple sand grains may be described as smooth (Fig. 7), rough (Figs. 4 and 8), glassy (Fig. 8), frosted (Figs. 6 and 7), pitted (Fig. 4), and stained. It is not impossible to find all of these in the same sand.

55. If the character of the surface bears any relation to the origin of the sand, then it would seem that the mixture of the above surface types in one sample would indicate that the grains may have been derived originally from several different types of deposit, and that they have not been worked over sufficiently long in the environment in which they are now found to have had the character of that type impressed upon them.

56. Frosted surfaces were noticed chiefly in marine and modern dune sands, although they were by no means common in

the latter. The best example of this type of surface is to be seen in the round grains of Ottawa, Ill., sand (Fig. 27), a marine deposit whose grains may show inherited characters. The St. Peter's sandstone from Wisconsin (Fig. 22), of the same age as the Ottawa sand, also shows them. Although frosted sand grains may be abundant in formations which as now found represent marine deposits, there is a decided probability that this characteristic may be inherited from a previous and entirely different environment.

57. Pitted grains are not confined to any type of sand, but they are more numerous in sizes from 70 mesh and coarser, as though the pitting might be due to mechanical causes, such as the grains being knocked together. In some cases it may be caused by solution, particularly in calcareous sands (Fig. 29).

Mineral Composition.

58. The total number of different minerals found in sands is quite large, but in the majority of sands the grains are mostly quartz. Mica is fairly abundant in some foundry sands, and some show an abundance of rock fragments in the coarser sizes.

59. Among the notable exceptions in which grains other than quartz predominate, may be mentioned volcanic sands, composed largely of fragments of volcanic glass or pumice, coral sands (Fig. 8) which are composed almost exclusively of shell and coral fragments, and gypsum sands (Fig. 16) made up almost entirely of grains of gypsum. These "exceptional" sands, however, are not used in foundry work.

60. Fig. 17, representing a dune sand from California, is interesting because of the large number of dark minerals which it contains and which increase greatly in the finer sizes. Thus, the sample caught on the No. 200 sieve contained about 15 per cent magnetite. Further determinations made for us by E. B. Mayo showed abundant amphibole, as well as small amounts of feldspar, zircon, rutile, epidote, hypersthene, apatite, ilmenite and calcite.

RELATION BETWEEN CHARACTER OF SAND GRAINS AND FOUNDRY WORK

61. The question naturally may be raised as to whether a study of sand grains is of any practical value.

62. While no detailed studies have been carried out along this line, the subject seems to have strong possibilities, since it

(Text continued on page 389)

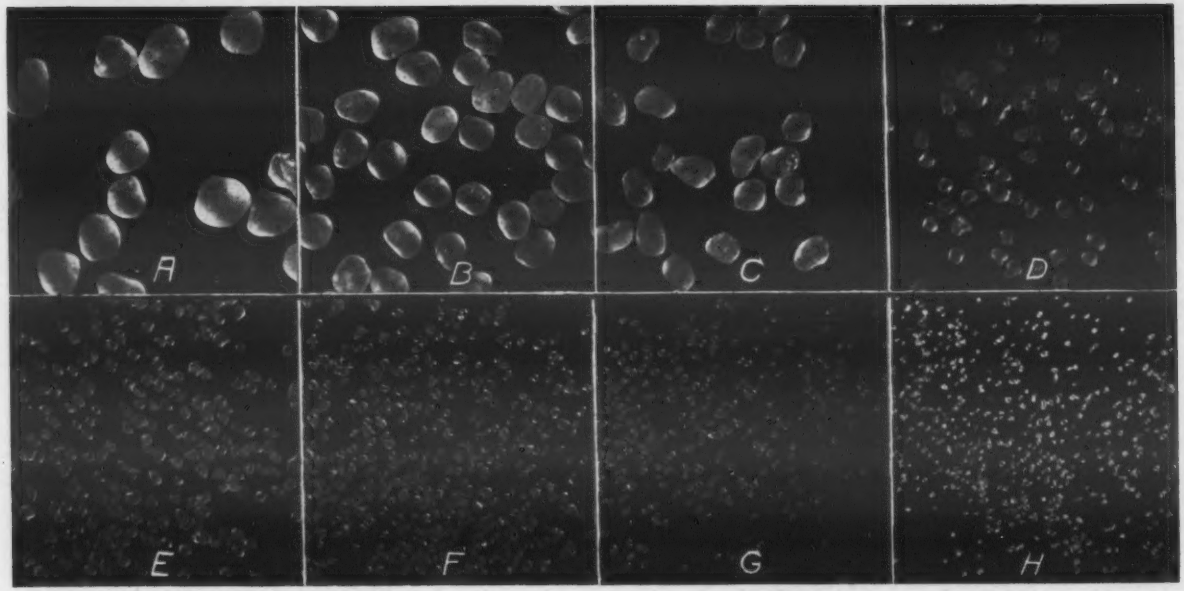

FIG. 27—OTTAWA, ILL., SAND, NO. 20-30 GRADE. SCREENED PRODUCT, ROUND GRAINS NOT PREDOMINATING BELOW 40 MESH. *A*: No. 20. *B*: No. 30. *C*: No. 40. *D*: No. 50. *E*: No. 70. *F*: No. 100. *G*: No. 140. *H*: No. 270.

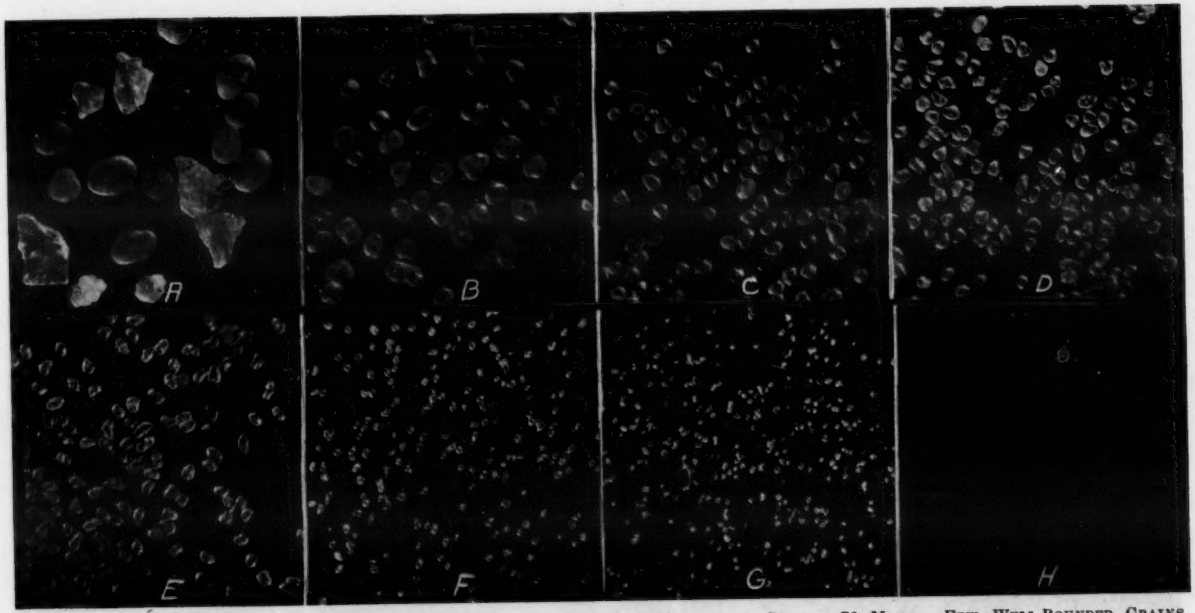

FIG. 28—A. F. A. STANDARD SAND FROM OTTAWA, ILL. THIS GIVES 95% BETWEEN THE 50 AND 70 MESH. FEW WELL-ROUNDED GRAINS. *A*: No. 30, 0.04%. *B*: No. 40, 0.04%. *C*: No. 50, 1.52%. *D*: No. 70, 96.22%. *E*: No. 100, 2.26%. *F*: No. 140, TRACE. *G*: No. 200, TRACE.

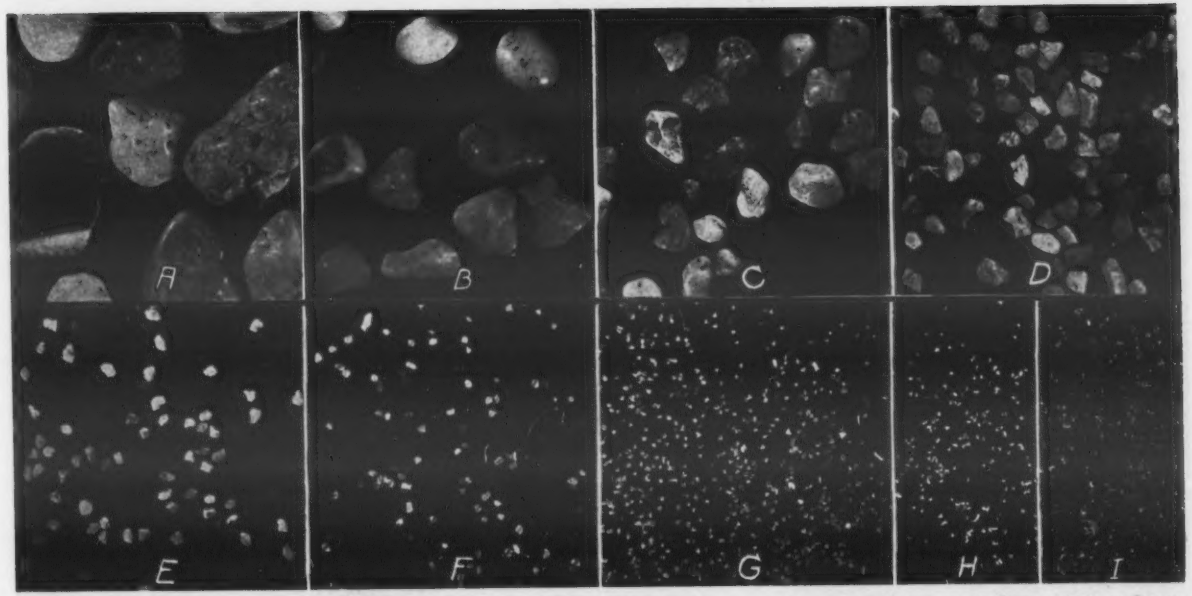

FIG. 29—CALCAREOUS BEACH SAND FROM MAUI, HAWAII. SOLUTION PITS ABUNDANT AND, ALTHOUGH MATERIAL IS SOFT, ANGULAR GRAINS ARE QUITE PROMINENT, EVEN ON NO. 70 AND NO. 40 SIEVES. *A*: No. 12, 1.5%. *B*: No. 20, 13.2%. *C*: No. 40, 72.7%. *D*: No. 70, 12.5%. *E*: No. 100, 0.4%. *F*: No. 140, 0.1%. *G*: No. 200, 0.1%. *H*: No. 270. 0.1%. *I*: PAN, 0.2%.

appears evident that the characters referred to above—such as shape, character of surface, uniformity of grain size, and kind of minerals present—cannot fail to affect such properties as permeability, strength, flowing qualities, absorption and refractoriness.

63. Sands having grains of a uniform size are likely to be more permeable than those with grains of mixed sizes, if the grains are not too fine. With a mixture of sizes, the small grains pack in between the large ones and permeability is reduced. The shape of the grains may also exert an influence on permeability, although much is to be learned on this point.

64. It seems very probable that in a bond-free sand, angular grains would interlock more closely than round ones, and thus two sands, agreeing closely in grain distribution, might show different permeabilities because of difference in the shape of the grains.

65. Incidentally, the study of the grains has brought out the fact that well-rounded grains are very rare, and so it is very difficult to get a sand composed even dominantly of grains of this shape. However, if the larger sizes are round or nearly so, the smaller ones are apt to be equidimensional rather than elongated, and therefore they may exert an effect similar to that of rounded ones (Figs. 23 and 27), since the shapes of the larger grains often appear to be reflected by the smaller ones.

66. If one compares the illustrations of the different sands, which were all photographed with the same magnification, it will be noticed that there sometimes appears to be a difference in size of sands retained on the same sieve, say, No. 70. There are two reasons for this. Most of these sands were run through the fineness test before the No. 50 sieve had been introduced in the series, and consequently everything between Nos. 40 and 70 was caught on the latter. Another and more important reason is that in one sand the grains between the 40 and 70 sieves may be nearer the 40, while in another they may be closer to the 70 sieve in size.

67. The presence of elongated grains may also produce a misleading appearance, and some of the grains on a given sieve may *look* larger than they really are, because of their elongated character. They were small enough to go through the next coarser sieve endways, but could not have gotten through any other way. The best sizing appears in the case of those sands whose grains approach equidimensional form.

68. We have much to learn still regarding the relation of

grain shape to strength, and there seems no doubt that there is a relationship. What tests have been made thus far indicate that rounded grains seem to give greater strength than angular ones.

69. Aside from this, however, it would appear that the character of the grain surface might exert an influence on the strength, because the bonding substance might adhere to one type of surface better than to another. This could apply to artificial bonding materials as well as to natural clays. Here again we have no data, and it is a problem which calls for investigation.

70. We also venture to suggest that the shape of the grains may effect the "flowing" qualities of a sand, for, assuming that we have two bonded sands of uniform texture, we may ask which would flow the easier under pressure, the one with smooth surface and rounded and sub-angular grains, or the one with angular particles. Rounded grains might get more uniformly coated with bond in mulling than do angular grains.

71. The study of sand grains may also throw some light on the refractory qualities of the sand. If composed largely of quartz fragments, the "grain" is likely to be quite refractory; but if there are many grains heavily stained by iron oxide, or compound grains cemented by either iron oxide or lime carbonate, or many grains of iron bearing silicates, the refractoriness would be lowered. Angular grains, with their sharp points, probably would flux more readily than round ones.

Effect of Compound Grains.

72. This is a feature which we believe may have been overlooked, and it should not be neglected, as some sands contain a considerable quantity of compound grains.

73. It is easily seen that a compound grain, whether it represents a piece of open sandstone or an aggregate of small sand grains which have become cemented together, must contain a considerable amount of pore space. These pores, then, are capable of absorbing water, oil or any other liquid, which after absorption becomes inert so far as its action as a binder is concerned.

74. We can conceive of a clay-free sand which, so far as its texture is concerned, would make a good core material, but which because of numerous compound grains absorbs an abnormal quantity of oil, and hence is an undesirable material to use. Fig. 24 probably is of this type.

CONCLUSIONS

75. The writers have endeavored to point out some features regarding sand grains which have received little attention in the foundry industry, and regarding which, it seems to them, some rather unwarranted conclusions have been drawn in the geological literature.

76. Viewed from the practical standpoint, it may seem that the value of the features discussed herein is one of purely scientific interest. Yet, considering the matter in the light of facts determined and studied during the work of the Committee on Molding Sand Research, it would appear that no features, however insignificant they may appear, can be ignored, for it may develop that they exert an influence hitherto unsuspected.

DISCUSSION

A. A. GRUBB:[1] The authors of this paper are to be congratulated on the excellent piece of work they have done. There is another practical application that also deserves attention.

The difference in the surface texture of sands certainly hooks up with the difference in their behavior in the foundry, in two respects. In the core room, compound grains and simple grains of rough surface texture certainly would absorb more water and more linseed or other core oil.

Some years ago, about 1920, I believe—we reported* on such tests and found that the dye adsorption value seemed to measure the amount of oil required to bond a sand. Mr. Lane also has done similar work. The photographs which the authors show explain why some of these sands, which appear to be simple grains and otherwise suitable, are great absorbers of oil and so are not suitable for oil-bound cores.

The other practical consideration is this: Would not clay bond stick better to such a rough surface? There is a difference in the behavior of a smooth, polished grain sand and that of some of our river sands, and I am inclined to think that this possibly explains that difference. Is it not reasonable that clay would stick to the rougher surfaces better than to the highly polished surfaces of some sands?

[1]Grubb & Marshall, Columbus, Ohio.

*_Selection and Blending of Core Sands_, A. A. Grubb; TRANSACTIONS A. F. A. (1925), vol. 33, pp. 808-814.

WM. N. WALTZ:[2] On these compound grains, is there not a danger that under the heat they may explode because of sand on the surface of the casting?

DR. H. RIES: I am not sure about that. I do not think they necessarily would in all cases, but they might. I have no definite data on that group.

I am glad Mr. Grubb referred to that matter of bonding. I believe that the character of the surface exerts an influence in connection with the bonding qualities. Also, I am wondering whether the shape of the grain and the character of the surface may not have something to do with the flowing qualities in the sand. These are all points which will stand investigation.

G. OLSON:[3] With regard to the question about sand grains exploding, we all know that such a thing occurs. I would like to ask enlightenment on that point, if anyone can give it. We know that we find pitted castings on light work, and I believe that it is due to nothing else but sand grains exploding.

L. B. KNIGHT:[4] Is that pitted condition caused by the compound silica grains exploding, or is it not possibly due to an excess of bond at that point? I believe those little explosions will not be found with a sand that is uniformly bonded throughout, but frequently we have found that where a little clay ball or ball of new molding sand or clay gets up against the pattern, the explosive condition will exist.

I have seen a cylinder wall in which the gas from the explosion has caused a hole. I question whether it is the silica grain that is causing the trouble as much as the bond in the sand and the lack of uniform distribution of the bond.

DR. H. RIES: I believe it is perfectly possible for single grains to break under the action of rapid heating. I should think it would be quite natural for a fair-sized grain to snap apart if it is rapidly heated, and I was under the impression that that was quite generally recognized. Such a condition would give more fine material.

G. OLSON: I have been over in Sweden the last few years and I know that there they had to go through quite a bit of experimental work just because sand did not act right in the mold. We took some sand, went into a laboratory and found that some sand grains did explode and others did not. The sand had no bond whatever; it was new sand that had not been used. Nevertheless, some grains exploded and some did not. It was supposed to be silica sand, but the grains that exploded were not silica sand.

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[2]Crucible Steel Casting Co., Cleveland.
[3]Illinois Malleable Iron Co., Chicago.
[4]National Engineering Co., Chicago.

Permanent Mold Foundry Practice for Bronze Castings

By Henri Marius,* Lenoir City, Tenn.

Abstract

The term "permanent molds" in this paper is used to designate long-life iron molds. These are stated to have a metallurgical advantage over sand molds in increasing strength and increasing the ability of copper-tin alloys to hold more lead. Foundry factors are stated to be most important, the principal ones being correct pouring temperatures, guarding against porosity and oxidation, gating and risering, melting, mold-wall thickness, clamping of molds and the type of iron used in the molds. Each of these factors is discussed in detail.

1. The word "permanent" may not be a perfect technical designation of iron molds which now are commonly used in casting various bronzes, brasses, gray irons and aluminum alloys. By comparison with sand molds, however, considering their remarkable performance—having frequently a life of close to 4000 castings and, in the case of aluminum alloys, exceeding this figure by several thousands—we cannot be far wrong in calling such molds permanent molds, be they made from gray iron, steel or other materials.

Metallurgical Advantage of Permanent Molds

2. The chief metallurgical claim of permanent molds is their chilling effect. Thanks to this, they produce castings of an exceptionally fine homogeneous microstructure, free from metallic segregations or burned-in sand and, for these reasons, castings of greater all-around strength and easier machinability. This is illustrated

* Lenoir Car Works.

Note: This paper was presented and discussed before one of the nonferrous sessions at the 1931 convention of the American Foundrymen's Association.

Table 1

COMPARISON OF PHYSICAL TEST DATA OF SAND-MOLD AND PERMANENT-MOLD CASTINGS GROUPED ACCORDING TO CHEMICAL ANALYSES.

GROUP 1.*—Chemical Composition of Heats Grouped Together.

Heat Nos.	Thickness† Of castings test bars were cut from in inches.	Weight† in lbs.	No. pcs.**	Sand Cast: Elast. limit, lbs. per sq. in.	Sand Cast: Ult. tens. strength, lbs. per sq. in.	Sand Cast: Percent elong. in 2 in.	Permanent-Mold Cast: Elast. limit, lbs. per sq. in.	Permanent-Mold Cast: Ult. tens. strength, lbs. per sq. in.	Permanent-Mold Cast: Percent elong. in 2 in.
40–26	1½	175	2	17,440	28,210	16	20,050	32,000	17.5
53–26	1½	120	3	17,930	30,300	17	20,000	35,000	20.0
68–27	2	200	3	16,410	28,100	16	20,500	33,650	19.0
102–27	2½	150	4	15,900	27,480	14.5	20,750	33,350	15.5
103–28	1	50	4	17,620	29,600	19	20,500	33,800	19.0
120–28	1	40	2	18,750	29,450	18	20,000	34,750	20.5
130–28	3	240	4	14,150	19,000	11	18,700	29,420	14.0
9–29	1¼	75	2	13,070	16,130	5	20,100	26,730	7.5

Average permanent set in fraction of an inch—Under 65,000 lbs. load on one-inch cubes—

Sand-cast 0.184 Permanent-mold cast 0.162

*Cu 77.50 to 80%; Sn 7 to 8%; Pb 11.50 to 13.50%; Zn 0.50 to 1%; Sb 0.10 to 0.35%; Undetermined 0.10 to 0.30%.

(Continued on next page)

Table 1 (Continued)

COMPARISON OF PHYSICAL TEST DATA OF SAND-MOLD AND PERMANENT-MOLD CASTINGS GROUPED ACCORDING TO CHEMICAL ANALYSES—(CONTINUED)

GROUP 2.††—Chemical Composition of Heats Grouped Together.

32-26	2	200	4	15,000	23,040	9	18,500	25,150	11
70-26	1½	120	4	15,350	24,000	12	18,000	27,150	14
76-27	1½	175	3	16,670	23,250	7	17,600	26,750	8.4
4-28	3	240	4	14,400	18,600	6	18,700	27,800	13
6-28	2½	150	2	12,000	22,450	12	14,200	23,700	12
14-28	1	40	2	15,900	26,650	14	17,350	28,000	13.5
26-29	1½	75	2	14,170	18,850	8	19,250	27,740	10.5

Average permanent set in fraction of an inch—under 65,000 lbs. load on one-inch cubes

Sand-cast 0.240 Permanent-mold cast 0.204

††Cu 70 to 72%; Pb 20 to 22.5%; Sn 5 to 6%; Zn 0.70 to 1.30%; Sb 0.35 to 0.60%; Undetermined 0.15 to 0.35%.

GROUP 3.*†—Chemical Composition of Heats Grouped Together.

M20-26	1½	30	3	17,200	36,000	29	18,700	38,300	28
M48-26	1	15	2	20,050	34,900	24	21,300	37,000	20
M72-27	1	10	2	20,100	35,000	24	21,100	38,700	21
M77-27	2	120	4	18,300	35,500	32	20,000	40,150	32
M90-28	2½	100	4	17,940	29,760	23	19,380	34,000	21
M95-28	1½	90	3	17,700	30,200	17	18,150	34,600	18
M104-28	1½	75	4	17,650	31,500	22	18,500	35,000	22
M109-28	2	50	3	15,000	25,400	14	17,800	29,430	18
M19-29	1½	75	2	15,080	16,930	6	21,860	31,660	10
M21-29	1½	40	2	16,000	18,600	5.5	21,500	26,300	4

*†Cu 85 to 87%; Sn 6 to 7%; Pb 3.5 to 5%; Zn 2 to 3%; Undetermined 0.0 to 0.2%.

NOTE: Diameter of test bars for all three groups was 0.505 inch.

†Thickness and weight of castings from which test bars were cut.

**Number of pieces tested in order to obtain average.

in the data of Tables 1 and 2, comparing sand-mold and permanent-mold castings.

3. The results of physical tests contained in Tables 1 and 2 are representative of actual foundry practice over a period of four years. They have been gathered together in order to express in figures (at least insofar as strength is concerned) the betterment in quality of bronze through permanent molding, as compared with sand molding.

4. All test bars were cut from actual castings, such as bearings, bushings, etc., and each permanent-mold casting, with the corresponding sand-mold casting from which test bars were cut, were of identical pattern, poured from the same heat from the same ladle. The test bars were cut from exactly the same position in each casting, which was done in order to have as much of an accurate, true physical representative test of the castings rather than the test bars, which are not always true representatives of the physical properties of the castings themselves.

5. As may be noted from the limits of variations of the chemical analyses and results of physical tests of the various test bars, no special attention or particular care were given these test heats. They were picked at random and they represent good, bad and indifferent heats. In each case the furnace charge was composed of 98 per cent good clean scrap and 2 per cent new metal.

6. In the case of Table 2, the value of the hardness figures given must be read in conjunction with the data of Table 1 to be appreciated, for part of the small increase in hardness is the natural result of finer, denser microstructure and a corollary expression of greater all-around strength as evidenced by higher elastic limits, ultimate tensile strengths and elongation as shown in Table 1.

COPPER-TIN ALLOYS

7. An example is in the field of simple leaded bronzes, now in unreasonably high vogue among wearing alloy manufacturers and users. Permanent molds, in addition to the above improvements due to the chilling effect on fracture, also increase the power of the copper-tin alloys to hold in more lead.

8. This is caused by the tin combining with a greater portion

Table 2

BRINELL HARDNESS OF CASTINGS OF TABLE 1.

GROUP 1.*—Chemical Composition of Heats Grouped Together.

Heat Nos.	Thickness,† in inches.	Weight,† in lbs.	Depth.** in inches.	—Brinell Hardness No.— Sand-Cast		Permanent-Mold Cast
40-26	1½	175	¼	62		66
			1	58		64
				60	Avg.	65
53-26	1½	120	¼	59		63
			1	55		61
				57	Avg.	62
68-27	2	200	¼	60		66
			1¼	54		65
				57	Avg.	65.5
102-27	2½	150	¼	58		61
			1¼	54		61
				56	Avg	61
103-28	1	50	¼	61		67
			½	61		67
				61	Avg.	67
120-28	1	40	¼	65		69
			½	64		70
				64.5	Avg.	69.5
130-28	3	240	¼	62		64
			1¼	50		64
				56	Avg.	64
9-29	1¼	75	¼	48		59
			1	44		59
				46	Avg.	59

*Cu 77.50 to 80%; Sn 7 to 8%; Pb 11.50 to 13.50%; Zn 0.50 to 1%; Sb 0.10 to 0.35%; Undetermined 0.10 to 0.30%.

NOTE: See Table 1 for analyses of metal of the three groups.
†Thickness and weight of castings from which test bars were cut.
**Depth under skin of castings where tests were made.

(Continued on next page)

Table 2 (Continued)

BRINELL HARDNESS OF CASTINGS OF TABLE 1.

GROUP 2††—Chemical Composition of Heats Grouped Together.

Heat Nos.	Thickness,† in inches,	Weight,† in lbs.	Depth,** in inches.	Brinell Hardness No. Sand-Cast		Brinell Hardness No. Permanent-Mold Cast
32-26	2	200	½	57		60
			1	50		57
				53.5	Avg.	58.5
70-26	1½	120	½	58		57
			¾	53		57
				55.5	Avg.	57
76-27	1½	175	½	58		60
			¾	54		60
				56	Avg.	60
4-28	3	240	½	54		61
			1½	47		60
				50.5	Avg.	60.5
6-28	2½	150	½	54		59
			1½	52		58
				53	Avg.	58.5
14-28	1	40	½	53		59
			¾	53		59
				53	Avg.	59
26-29	1½	75	½	50		60
			1	48		60
				49	Avg.	60

††Cu 70 to 72%; Pb 20 to 22.5%; Sn 5 to 6%; Zn 0.70 to 1.30%; Sb 0.35 to 0.60%; Undetermined 0.15 to 0.35%.

NOTE: See Table 1 for analyses of metal of the three groups.
†Thickness and weight of castings from which test bars were cut.
**Depth under skin of castings where tests were made.

(Continued on next page)

Table 2 (Continued)

BRINELL HARDNESS OF CASTINGS OF TABLE 1.

GROUP 3.*†—Chemical Composition of Heats Grouped Together.

Heat Nos.	Thickness,† in inches.	Weight,† In lbs.	Depth,** in inches.	Brinell Hardness No. Sand-Cast		Brinell Hardness No. Permanent-Mold Cast
M20-26	1½	30	¼	60		62
			¾	55		64
				57 5	Avg.	63
M48-26	1	15	¼	61		70
			¾	65		67
				63	Avg.	68 5
M72-27	1	10	¼	61		61
			¾	61		61
				61	Avg.	61
M77-27	2	120	¼	59		60
			1	57		60
				58	Avg.	60
M90-28	2½	100	¼	65		63
			1¼	57		63
				61	Avg.	63
M95-28	1¾	90	¼	57		67
			1	55		66
				56	Avg.	66 5
M104-28	1½	75	¼	61		62
			1	57		62
				59	Avg.	62
M109-28	2	50	¼	55		65
			1	53		65
				54	Avg.	65
M19-29	1½	75	¼	58		58
			¾	51		57
				54 5	Avg.	57 5
M21-29	1½	40	¼	50		55
			1	48		55
				49	Avg.	55

*†Cu 85 to 87%; Sn 6 to 7%; Pb 3.5 to 5%; Zn 2 to 3%; Undetermined 0.0 to 0.2%.

NOTE: See Table 1 for analyses of metal of the three groups.
†Thickness and weight of castings from which test bars were cut.
**Depth under skin of castings where tests were made.

of copper, thus promoting the formation of a larger amount of a finer network of copper-tin alloy, which by solidifying first retains the lead, evenly distributed throughout the mass, in form of fine globules until the lead, in its turn, reaches the state of solidification. In this manner, 5 per cent tin can hold in as much as 40 per cent lead in a copper-base alloy, without segregation.

9. Unfortunately, bronzes with such a low percentage of tin and such a high percentage of lead can have only a limited industrial application, because of their lack of sufficient hardness, resilience, tensile strength and compressed strength.

10. In recent years highly leaded bronzes cast in iron molds have found great favor with the railroads, where they are extensively used as wearing alloys for locomotive bearings. It is our opinion that highly leaded bronzes will find a more useful application in the manufacture of car-journal bearings, for it is possible to produce from them a harder, stronger and more rigid bearing than the present one, capable of taking a highly polished surface of such anti-frictional qualities as to eliminate the necessity of the present lining alloy or babbitting.

RED BRASSES

11. The chief advantage of permanent molds in the field of red brass is that they correct porosity and the formation of dendrites commonly found in sand-cast red brass of unbalanced composition, in which the white metals such as tin, lead or zinc are abnormally low or abnormally high and out of balance.

ALUMINUM ALLOYS

12. As for the newer but rapidly expanding alloys of aluminum, they are among the easiest to cast in permanent molds. As a matter of fact, any kind or composition of nonferrous alloys can be cast in iron molds, provided the design of castings is compatible with this new molding process.

METALLURGICAL PROBLEMS

13. The metallurgical problems surrounding permanent molding are few and unimportant. In the field of bronzes the one question that requires some explanation is that of hardness. The

average foundryman may feel that the chilling effect of the iron molds is liable to produce hard and brittle castings, as is the case with gray iron and steel. Such, however, is not the case.

14. Hardness in simple bronze is primarily a function of tin, which forms with copper several alloys, some hard, some soft. When we take into consideration the chemical valences of these two metals, we find that the two extremes of these binary copper-tin alloys correspond to formulas Cu_4Sn and Cu_2Sn_2, respectively. The latter is called the "eutectic" because of its lower melting point, and it is softer than the richer in copper, Cu_4Sn. In fact the eutectic is little harder than pure copper, so that in the end a simple bronze is hard in proportion to the amount of Cu_4Sn it contains.

15. Now the chilling effect of the iron mold causes nearly all, if not all, of the tin to remain in the bronze in the form of Cu_4Sn, whereas in the sand-cast alloy the slow solidification has almost the opposite effect. Therefore, the same bronze composition, when cast in iron molds, will be harder than the sand cast, only in proportion to the excess of Cu_4Sn it contains plus that smaller portion of hardness derived from the greater density of mass of the chill cast alloy.

METALLURGICAL CONSIDERATIONS

16. While successful permanent molding is not so much a matter of metallurgical skill, nevertheless there are certain tricks of foundry practice that have to be acquired from experience alone and mastered before iron molds will give the desired results. As a general guidance rather than absolute rules, some high points which are strictly observed in our foundry practice for casting brass and bronze are given below, starting with the often-guessed-at pouring temperature.

CORRECT POURING TEMPERATURES IMPORTANT

17. Diligent observance of the correct range of casting temperature for each type of brass and bronze, so that the melt is not poured into the molds too cold nor too hot, is always an important factor in the production of sound castings independent of the molding process used.

18. With iron molds the ranges of pouring temperatures are

higher by 75 to 100 degs. Fahr. than the corresponding ranges when sand molds are used. For example, the pouring temperature range of sand-cast locomotive bearings of 80-10-10 composition is acknowledged to be between 1700 and 1800 degs. Fahr. The corresponding range, when iron molds are used, will prove to be between 1775 and 1850 degs. Fahr.

19. Since the molten alloy loses heat and, of course, fluidity incomparably faster in an iron mold, it is necessary that it possess these two physical conditions in a larger degree to start with in order for the metal to reach all parts of the mold before it becomes cold and sluggish, and in order to give a sound casting of sharp, well-defined contours free from red spots, cold shuts, wrinkles and draws under the riser and gate—defects characteristic of cold metal. Likewise, the very rapid solidification of the iron-mold cast alloy is a great hindrance to the release of entrapped air or gases formed in the mold or absorbed by the charge during melting. This difficulty becomes particularly apparent in the production in iron molds of castings having thin sections.

20. On the other hand, should the alloy be poured too hot, the erosion on the mold face and the heating of same will be unnecessarily great and will hasten the failure of the mold. The castings will come out with honeycomb patches here and there, caused by volatilization or oxidation of carbon particles peeled from the surface of the mold at those areas where erosion and overheating have been the greatest.

POROSITY AND OXIDATION TO BE GUARDED AGAINST

21. Correct casting temperature then becomes an important factor in the production of sound castings. However, the importance of melting the alloy under proper conditions should not be neglected.

22. This precaution is necessary for, while it is true that iron molds entirely eliminate casting losses which commonly occur with sand molding—either from badly prepared sand, unsuitable materials, or, as is more often the case, from lack of molding skill—regarding defects of porosity and oxidation resulting from faulty melting, the best to be expected from the iron molds is that such defects will be made less apparent and less harmful in the castings by reason of a very much finer and more homogeneous microstructure.

23. In order to help further this corrective power of the iron molds on porosity and over-oxidation from faulty melting or from any other cause, a thorough stirring of the melt before pouring will always be found beneficial. This benefit is secured when the stirring is performed in an intelligent manner, with an iron rod having the shape of a paddle, imparting to the liquid alloy in the ladle a somewhat centrifugal motion which facilitates the releasing of absorbed or neutral gases. The light and stable oxides of zinc and tin and impurities such as alumina and sulphides will come to the surface to be skimmed away with the rest of the slag.

24. In the case of copper and lead oxides, since their molecular weights are almost as great as those of brass or bronze, they are easily diffused and held throughout the mass of the melt, thus becoming far more difficult to extract by stirring only. In such case a small amount of phosphor-copper or magnesium will help effectively the purpose of stirring, by reducing a good part of these oxides.

ENTIRE MELTING PROCESS SHOULD BE WATCHED CLOSELY

25. However, prevention being better than cure, it is best from every standpoint to watch diligently over the whole process of melting, from the time the various metals are charged into the furnace to the moment the heat is ready to be tapped out, and to prevent the expensive and ineffective doping of the melt with fluxes of very doubtful value—by which method the average foundryman tries to retrieve a carelessly melted heat.

IDEAL MELTING CONDITIONS

26. Ideal melting conditions can only be obtained, of course, when melting is done in a perfectly neutral atmosphere in which the amount of heat transmitted to the charge to be melted remains constant per time unit throughout the melting period. Unfortunately, such an ideal condition cannot be attained even with the best type of melting furnaces and fuels and most skilled supervision. Under ordinary practical, every-day foundry conditions, the melting atmosphere is more likely to be reducing or oxidizing, or be made to vary from reducing to oxidizing, and *vice versa*.

27. The essence of good melting practice, then, becomes strictly a matter of learning how to control and intelligently

regulate this atmosphere between reasonable limits to suit the needs of the charge to be melted. A good deal of technical work at the laboratory often is lost or sidetracked in careless melting in the foundry, and to this we must attribute a majority of casting losses, the most prominent of the lot being porosity and oxidation.

TOP GATING VERSUS BOTTOM GATING

28. Assuming that the alloy is in the right condition at the time of pouring, both from the standpoint of melting and of temperature, we come to the gating arrangement through which the metal must pass to fill the mold properly.

29. The advisability of a bottom or top gate has always been a debatable question. While one foundryman will swear by the top gate, another will tell you he will not use anything but a bottom-pouring gate.

30. Undoubtedly each one of these two methods of gating possesses certain particular advantages which the other lacks. For example, the top gate is always the least expensive because it requires less metal, and there may be certain types of castings of such design that will make the use of a bottom gate a rather complicated affair and for that matter not worth while.

Advantages of Bottom Gating

31. We, however, feel sure there are few foundrymen who have had extensive experience with both methods of gating who will not agree with us that the bottom gate is the best for general all-around purposes in obtaining uniformly good results. In our experience with permanent molds we have had the opportunity to try out both top and bottom gating methods, and we have come to the conclusion that the bottom gate is almost necessary for mass production of sound castings in such molds, for several reasons, the principal ones being as follows:

(a) The danger of undue erosion and overheating of small areas of the mold surface, caused by the rapid and direct flow of the hot molten metal, is avoided. It affords a better upward draft for occluded and generated gases from volatile matter in the mold coating.

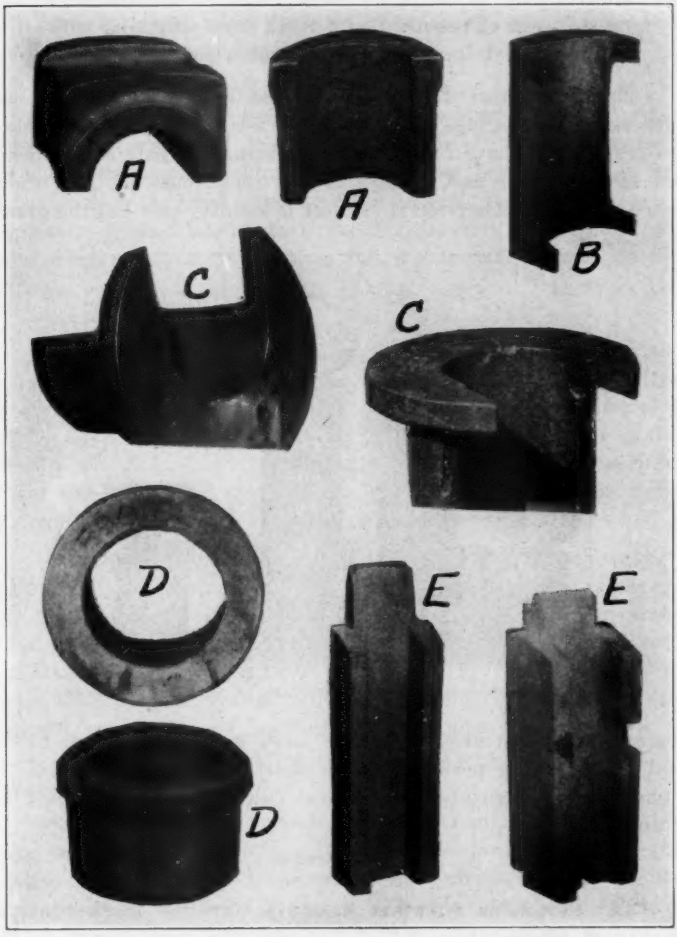

FIG. 1—PERMANENT-MOLD CASTINGS FOR RAILROAD WORK.
A, A: BACK-END MAIN-ROD BRASSES FOR LOCOMOTIVES.
B: TRAILER TRUCK BEARING.
C, C: FLANGED CROWN BEARING FOR LOCOMOTIVES.
D, D: FLOATING BUSHINGS.
E, E: LOCOMOTIVE SHOE WEDGE.

(b) The metal coming up from the gate at the bottom rises in the mold evenly and gently and lays on the walls of the mold, and there is no splashing with its subsequent formation of cold shuts and air pockets.

32. In the manufacture of railroad bronzes for locomotives such as crown bearings, back-end-rod brasses, floating bushes, shoe wedges, etc., we have found that by placing the gate at the heaviest section of the casting, it also functions somewhat as a riser. Since this heaviest section is the last to solidify and has the great-

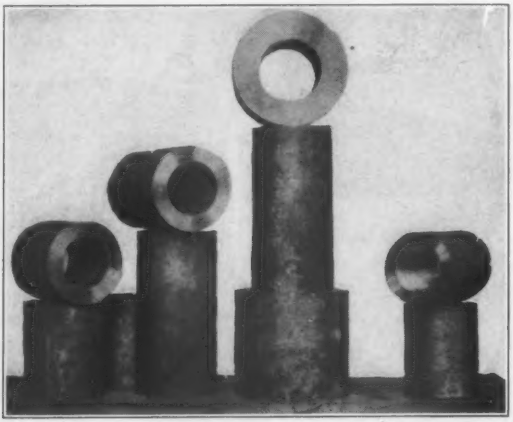

FIG. 2—PHOSPOR-BRONZE BUSHING CAST IN PERMANENT MOLDS

est amount of shrinkage, the gate feeds it with hot metal to the end of its setting period, however short that period may be. A number of permanent-mold railroad castings are shown in Figs. 1 and 2.

THE SPRUE

33. Particular attention should be directed to the gate or that part of the sprue which connects the gate proper to the casting. It should have a cross-section area equal to that of a circle whose diameter is not less than 0.85 times the thickness of the casting at that part, and a length of not less than 1½ inches.

34. These requirements are necessary for the obvious reason that the gate controls the thickness of that part of the mold which separates the feeding gate from the casting. Thus, this

section of the mold, being exposed to a cross heat from the casting and the feeding gate at the same time, should be rather thicker than any other section of the mold in order to avoid undue overheating and disintegration.

35. Furthermore, when the sprue passage is too narrow, the danger of the metal freezing up or setting up ahead of time, causing shrinkages and draws, always is present. If the gate is too short, the metal rushing down from the feeding gate strikes at the area of the mold opposite the gate with greater force, causing sharp erosion and subsequent volitilization of carbon particles which translate themselves into honeycomb patches on the casting.

POURING

36. A much neglected feature of foundry practice, often noticed even in the best regulated foundries, is the pouring of a mold. Important points such as speed, volume of flow and steadiness are not given due attention. Haphazard pouring is the cause of far more casting losses than is realized by the average foundryman.

37. Thus, losses from such defects as piping, shrinkage, cracks, etc., regularly attributed to inadequate risers, often are due to the apparently foreign cause of too fast pouring. Sand spots and pin holes may come from sand entrained from the pouring basin, cut loose from there by an unsteady and hard flow of metal see-sawing all over a rather soft pouring basin. Seams and wrinkles usually found on large castings may be caused not so much by cold metal as by too small and intermittent a stream of metal.

38. In pouring iron molds we are particular to start with a large and rapid stream of metal, slowing down gradually and gently as the mold fills up, in such a continuous way that by the time the metal begins to appear in the riser the stream of metal is not larger than the thickness of a pencil. (See Figs. 9, 10.)

39. By pouring thus we have eliminated the expensive necessity of providing numerous large risers to take care of the greater shrinkage per time unit characteristic of chill cast alloys. This is because the heavy section provides the necessary hot metal required to feed the faster setting sides of the casting and, in turn, the slow flow of hot metal toward the end of pouring takes

care of the heavy section, which is fed last because of our gating arrangement.

Heavy Castings Poured Without Risers

40. Under these conditions it is quite possible to pour any kind of heavy castings without any riser at all, provided the casting is gated at its heaviest section with flanges (if any) up, and with the pouring slow enough at the end as explained above.

41. This procedure, however, has the drawback of slowing down pouring operations generally, often to such an extent as to cause material inconvenience from the metal becoming too cold and sluggish in the pouring ladle. A happy medium is struck by the provision of having one riser in combination with the pouring cup, the two together forming a pouring basin.

42. Such a combination, aside from speeding up pouring operations, affords the valuable advantage of providing a second gate. Should the bottom gate become stopped up from any cause, the riser acts as a top gate, automatically preventing any stoppage from occurring in the pouring of the casting.

43. Figs. 3 to 7 illustrate the general arrangement of the gating and pouring basin combination of cast iron molds for various railroad bronzes in use at our gear plant. It will be seen

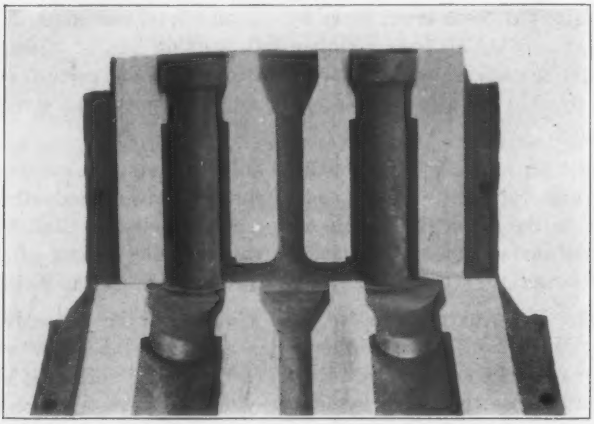

FIG. 3—DUPLEX PERMANENT MOLD FOR PHOSPHOR-BRONZE BUSHINGS, SHOWING CORES IN POSITION.

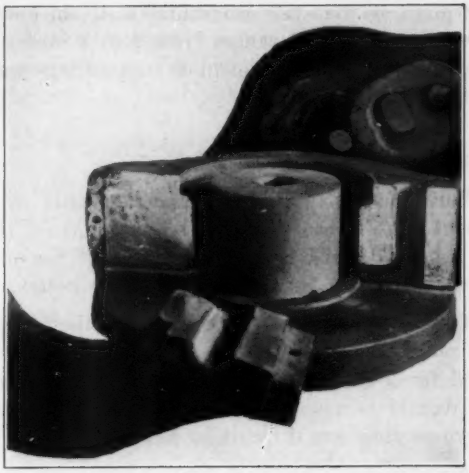

FIG. 4—PERMANENT MOLD FOR LOCOMOTIVE FLOATING BUSHING, SHOWING GATING ARRANGEMENT AND BASE PLATE ON WHICH MOLD PROPER RESTS.

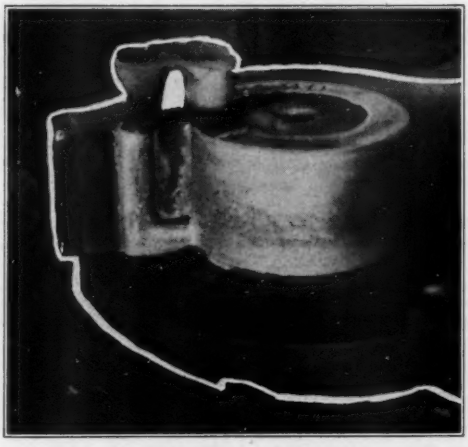

FIG. 5—PERMANENT MOLD WITH CASTING IN PLACE.

from these pictures that the all-around wall thickness of these molds is quite generous. It ranges from 2 to 3 inches, depending on the mass of the casting the mold is supposed to make and the speed of production desired.

WALL THICKNESS OF MOLDS

44. Wall thickness plays an important part in the design of permanent molds, because it directly controls the pouring schedule. As a rule, the heavier the walls of the mold, coincident with the necessary ease of handling, the better.

45. Massive molds permit a greater number of pourings in a given period of time, which means that a lesser number of molds are required for a given output of castings of the same pattern. Again, the danger is avoided of the molds getting overheated to the point where they are difficult to handle.

46. Our experience has been that the life of a mold is much shorter when the temperature of its mass runs above 800 degs. Fahr. after each pouring than the mold which is heavy enough to absorb all the heat given up by the casting and stay below the 850

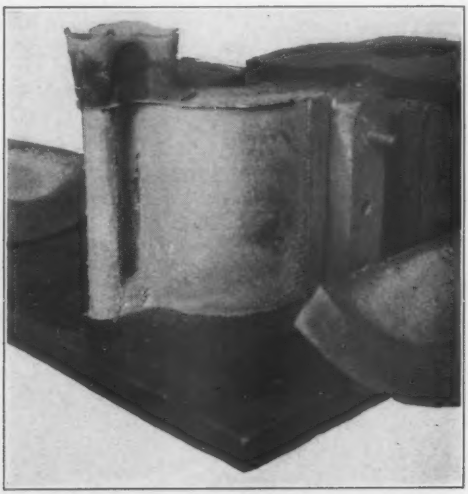

FIG. 6—PERMANENT MOLD FOR LOCOMOTIVE CROWN BEARING AT "SHAKING DOWN" OF MOLD. THE CASTING IS SHOWN WITH ATTACHED GATE AND RISER, WITH GATE PART OF MOLD REMOVED.

degree mark. In the case of molds for bushings, massive walls provide another advantage. When the molds develop surface cracks or become rough from erosion after a period of service, they can be re-bored or refinished at little cost and used again.

MOLD THICKNESS RELATED TO WEIGHT OF CASTING

47. The relation of mold thickness to the weight of casting and the pouring schedule may be expressed by the empirical formula*

$$\frac{W\ (t-t^1)}{Pr. \times Rt.} \times \frac{1}{H} = T$$

in which W = Mass or weight of casting
t = Pouring temperature of same
t^1 = Temperature of the casting at "shaking out"
Pr. = Time in minutes the casting is desired to remain in the mold before it reaches shaking-out temperature
Rt. = Maximum allowable increase in temperature of the mold from heat absorbed from the casting
H = Length or height of casting
T = Thickness of mold wall in inches

* NOTE: This empirical formula was arrived at by noticing the fact that, after pouring a certain casting, the mean temperature of the mass of the mold multiplied by the total mass of the mold itself is equal to approximately two-thirds of the product of the pouring temperature of the casting minus its shaking out temperature and this difference in temperature multiplied by the mass of the casting. The other one-third of the original amount of heat is dissipated through radiation while pouring and during the setting period.

To better illustrate the meaning of this formula we give the following problem from our own practice: Suppose we want to know the thickness of the wall of a mold to cast locomotive crown bearings with a composition of 78 per cent copper, 7.50 tin and 14.50 lead, each weighing 175 pounds and with a length (of greatest dimension) of 13 inches.

The pouring temperature of such a composition in iron molds is 1825 degs. Fahr. The temperature of the casting at "shaking out" must not be over 575 degs. Fahr. (mean temperature at the surface and the core of the casting), otherwise the casting is liable to crack or break while it is taken out from the mold; and it is desired that the casting does not remain in the mold over 12 minutes before it reaches the "shaking out" temperature.

Now, in order for the mold to take care of the heat remaining in its mass from subsequent pourings, its mean tem-

perature must not be raised to over 500 degs. Fahr. to start with, from heat absorbed from the casting during the "setting period," otherwise the mold is liable to become overheated, which means rapid deterioration. We have, then

$W = 175$ lbs. $\quad Pr. = 12$

$t = 1825 \quad Rt. = 500$

$t' = 575 \quad H = 13$

and, substituting figures for symbols in the formula, we have

$$\frac{175\ (1825 - 575)}{12 \times 500} \times \frac{1}{13} = 2.8 \text{ inches}$$

Clamping Permanent Molds

48. From the illustration it will be seen that our molds are free from any complicated device to hold their component parts together while pouring or to strip the casting from the mold after pouring.

49. Steel U-shaped clamps, at one end of which there is a set-screw bolt, serve for clamping purposes. For stripping we use an ordinary crow-bar with a sharp, flat end.

FIG. 7—ARRANGEMENT OF POURING BASIN AND TOP PLATE OF MOLD SHOWN IN FIG. 6. LEFT, SOLID IRON PLATE. RIGHT, IRON TOP PLATE WITH DRY-SAND POURING BASIN.

50. While the clamping of permanent molds still was at the experimental stage with us, several mold failures were traced to clamping these molds too tightly so they could not expand freely under heating.

51. The component parts of iron molds should be clamped together lightly, not any more tightly than is necessary to prevent these parts from springing apart and causing leakages or run-outs while pouring. After this the natural expansion from heat absorbed from the casting tightens them more and more, and it is important at this stage that the clamping rigging possess enough flexibility to give somewhat under the tremendous force of heat expansion.

FIG. 8—FLOOR OF PERMANENT MOLDS.

52. A very easy way to accomplish this flexibility is to drive a small wooden wedge lightly between the steel clamps and the mold. This wooden wedge acts as a cushion to mold expansion, thus making clamping flexible and "knocking down" of the mold easy.

WATER-COOLED VERSUS HEAVY-SECTION MOLDS

53. With the advent of permanent molding machines which may use water or air for cooling the molds after each pouring, the wall thickness has lost somewhat the importance it plays in the design of our present molds. It is very probable that the future improvements which are bound to be added to these machines from time to time will make our present permanent molds look very ancient indeed.

FIG. 9—POURING MOLD FOR LOCOMOTIVE CROWN BEARING. AT START OF POURING, WITH WIDE STREAM OF METAL. NOTE CLAMP ARRANGEMENT.

54. However, we believe it is time for the foundryman to stop and take a thorough stock of the net results of our over-mechanized era. It is quite possible he will discover that in many instances concerning some machinery it is a case of "robbing Peter to pay Paul."

55. In other words, he may find that his yearly output of saleable castings is not up to the production of his machinery, and while he may actually be saving on productive labor, he may be spending that much if not more in higher overhead accrued from maintenance and depreciation of a much more expensive but idle machinery than his real needs demand.

56. To further clarify this statement, we are giving these significant figures from our own practice: Using the type of

FIG. 10—POURING MOLD SIMILAR TO THAT SHOWN IN FIG. 9, BUT WHEN MOLD IS ABOUT FULL. NOTE LIGHT STREAM OF METAL.

iron molds shown in the accompanying illustrations, in a space of 30 by 100 feet and with a total force of six men who cannot claim to be skilled mechanics of any kind, we set up, pour and shakeout (including moving castings to the cleaning room) 130 to 150 molds representing 30 to 50 different pattern castings and a total weight of over 20,000 lbs., in an 8-hour shift.

57. For ease of handling, the component parts of each iron mold slide on an iron plate which forms part of the mold. The molds are used as needed, and at no time does it become necessary to move them from place to place unless they are worn out and have to be replaced by new ones. The whole outlay of molds is served by an overhead crane operated from the floor and a bottom-pouring ladle holding 750 lbs. of metal at a time.

PREPARATION OF MOLDS FOR CASTING OPERATION

58. Having given the salient points of our foundry practice concerning melting, pouring and mold gating, we come to the preparation of these iron molds at the start of operations. Before the mold is closed for the cast, it is preheated with an oil torch to a temperature of some 250 degs. Fahr. This is done in order

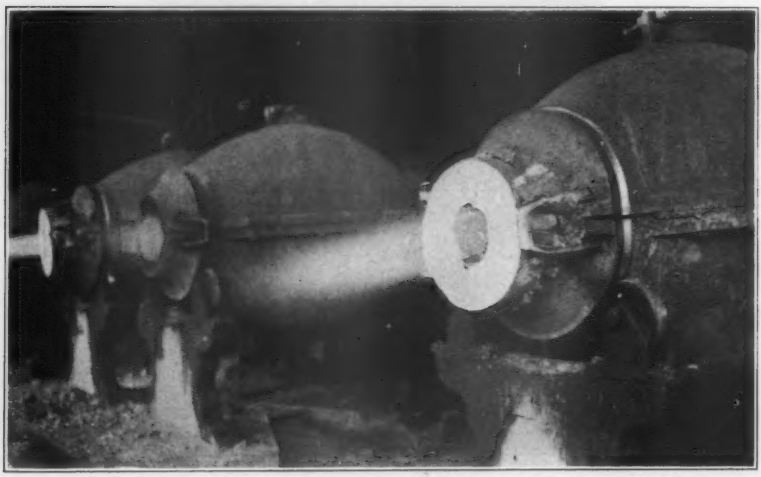

FIG. 11—BATTERY OF FURNACES USED IN MELTING.

to drive off any moisture that might have collected in the molds, and to help the flowing of metal at pouring.

59. Then a mixture of paraffin, lubricating oil and a small amount of plumbago is sprayed or applied with a brush over the face of the mold. The purpose of this application is two-fold. First, the greasy matter of the paraffin oil, assisted by the small diluted amount of plumbago, forms on the face of the mold a thin but protective film which acts in identical manner as do mold facings in sand molds. Second, the evaporation of the volatile matter in the oil cools the mold considerably between pouring intervals.

60. Heavy crude oils of coal-tar base are not so well suited for mold dressing because the deposited pitch on the face of the mold, after evaporation of the volatile matter in the crude oil, sticks to the face of the casting. This gives the casting a black, pitted appearance and otherwise causes trouble unless the mold is frequently and thoroughly scrubbed with some wire brush operation, not easy to perform while the molds are hot.

61. Clays and other compositions of silica base, while giving good results for casting metals and alloys of low melting point such as aluminum, are not suitable mold dressings for casting metals or alloys of high melting point such as red brass.

62. Kerosene, in which a certain amount of lamp black has been mixed, makes a good dressing, but it is explosive due to the low flash point of this oil, and for that reason it is dangerous to use on hot molds.

TYPE OF IRON IN MOLDS

63. All our permanent molds are made in our plant of hard, close-grain iron having a chemical composition as follows: Total carbon 3.00 to 3.25 per cent; combined carbon not less than 0.70; silicon not over 0.80; sulphur not over 0.15, manganese 0.55 to 0.80; phosphorus not over 0.40.

64. Hardness and density of mass, even at the expense of machinability, are two essential qualities for iron permanent molds in order to withstand erosion and gas penetration. We find that the best and cheapest way to obtain these two qualities is by keeping the total carbon fairly low and the combined carbon fairly high, and the melt very hot.

Annealing Should Be Avoided

65. Annealing of the molds in order to help machinability should be avoided at all costs. It is better to chip off hard corners than anneal the casting in order to render it soft and easy to machine, for by softening the molds we destroy their best quality and consequently shorten their life considerably.

Advantages of Gray Iron for Permanent Molds

66. One reason for our preference of gray iron as material for permanent molds is because of its low cost of manufacture. Also, the carbon in gray iron acts somewhat like a facing material, such as plumbago, tending to prevent the casting from sticking to the mold, as is the case with molds of carbon steel. By the same token, the necessity is avoided of applying on the face of the mold heavy dressing compounds which consequently contain objectionable volatile matter causing formation of unwelcome gas. Lastly, gray iron molds are not so apt to warp and become distorted from high heat, as is very often the case with ordinary carbon steels.

67. Eventually, however, we believe that it is in the realm of reality that alloy steels will eventually supersede gray iron and carbon steel as material for permanent molds, which will be cast in such a manner that the molds will not require any machining at all. At present this forms their greatest handicap.

DISCUSSION

W. F. GRAHAM:[1] It would appear that this paper deals chiefly with castings for bearing purposes, and not with thin-sectioned castings for pressure work. Some years ago I had occasion to observe and collaborate in some experiments on permanent-mold castings, and it was the observation that for thin-sectioned castings subjected to high pressures, the crystal formation of the metal cast in the permanent mold was not entirely satisfactory.

[1] Technical Director, Caskey Brass & Bronze Co., Philadelphia.

The cooling effect of the mold face produced a columnar crystal which would probably run across the full width of the section, making an unsatisfactory structure, as compared with the sand casting which would have mostly equi-axed crystals throughout the whole structure. Possibly some chilling effect on the outside produces a slight columnar crystal formation, but in general the crystals in the sand casting tend toward the equi-axed shape.

In other words, inclusions in the first type of structure would tend to remain on these crystal boundaries, and the pressure would have a free path through the defect.

That was simply an observation. It is no criticism of the permanent mold idea, but I should like very much to have someone comment on this.

H. M. ST. JOHN:[2] I have had practically no experience with the permanent-mold casting of brass or bronze alloys, outside of a very little purely laboratory experience. I do feel, however, that foundrymen in general should take a very active interest in this paper and in similar developments.

There may be a little tendency on the part of the sand foundrymen to resent the encroachments of permanent-mold castings of various forms. It seems to me that this sort of development should be welcomed, because there are other encroachments more serious to the foundry than this—such things as forgings, die castings and certain other types of stampings and parts built up of structural material.

These latter are taking work away from the foundry entirely. This is happening every day and we need not blind ourselves to it, in spite of the fact that we know there is some work which only the foundry can do.

Development of metal molds is a foundry development. It is the sort of development that tends to counteract the other encroachments of which I speak.

CHAIRMAN SAM TOUR:[3] So far as I know, there have been no successful commercial applications of the permanent molding of brass. The zinc fumes from brass condense so rapidly on the face of the mold as to spoil the surface of the casting after only a few casts.

This is the main drawback to the permanent molding of brass by the same process as the permanent molding of bronze, discussed in this paper. If we can find some way to stop the zinc condensation on the surface of the mold, then it will be perfectly possible to proceed to the permanent molding of brass castings.

Normally, in permanent-mold work the idea is to get not only rapid production but also to hold closer dimensions and get a smoother surface than in sand castings. If one were not interested in a smooth surface, permanent molding of brass might still be practical.

I might point out that most of the castings with which this paper deals are of a nature where close dimensional accuracy is not important,

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[2] Chief Metallurgist, Detroit Lubricator Co., Detroit.

[3] Vice-President, Lucius Pitkin, Inc., New York.

and where surface appearance as well is not of such great importance.

Paragraph 47 of the author's paper refers to the mold thickness as related to weight of casting. The empirical formula given for calculating the thickness of the mold wall is somewhat thrown out by the previous statement in the paper that it is desirable to have the mold walls as thick as possible.

The first paragraph of the note under the formula states how this formula was derived, "by noticing the fact that, after pouring a certain casting, the mean temperature of the mass of the mold multiplied by the total mass of the mold itself is equal to approximately two-thirds of the product of the pouring temperature of the casting minus its shaking-out temperature," and so on. It says, "The other one-third of the original amount of heat is dissipated through radiation while pouring and during the setting period."

This is not, in my opinion, a correct statement. The empirical rule, that the apparent increase in temperature is only about two-thirds that which would be expected from straight temperature considerations, is approximately correct; but the reason is not due to radiation. We must consider specific heat and the latent heat of fusion of bronze as compared with the specific heat of cast iron. The bronze cools so many degrees and the cast iron does not heat that many degrees because its specific heat is much higher than that of the bronze.

The interesting thing in the permanent molding of bronze in general is that it is becoming more and more popular, and we are going to hear more and more about it from now on. We have the developments not only of this type of permanent molding but also of the centrifugal type of permanent molding and the pressure type of pressure casting, or hot-press castings, as some are calling it now.

WRITTEN REPLY BY AUTHOR

H. MARIUS: Mr. Graham's comments on columnar and equi-axed crystallization in this case seem to me to be of mere laboratory interest.

What kind of inclusions does Mr. Graham have in mind? If it is gas inclusions he speaks of, we refer him to paragraph 19 of the paper, it it is oxides, we refer him to paragraphs 21 to 24, inclusive; if it is just slag, that is merely carelessness in skimming, which neither permanent molds nor sand molds can take care of *per se*. Possibly the following facts can better answer the query Mr. Graham has in mind.

The Southern Railway System, all through their shops, use standard permanent-mold-cast round and hexagon stick bronze 1 to 2 in. in diameter from which they cut out all kinds of locomotive steam fittings, subjected to a steam pressure of 225 to 250 lbs. with a superheat of 400 degs. Fahr. The composition of this stick bronze is approximately copper 86 per cent, tin 7 per cent, lead 5 per cent and zinc 2 per cent.

In our own shops we have subjected cylinders with 2 in. diameter, 3/16 in. wall thickness, 12 in. long (machined from bushings 2 in. diameter, 1/2 in. wall thickness, permanent-mold cast, chemical composition as above), to 350 lbs. hydraulic pressure without so much as a sweating through.

While we are on the subject of pressure, we wish to remind Mr. Graham that the essence of quality in pressure castings consists of fine grain and density of mass, two characteristics in which cast permanent-mold alloys rightfully excel.

We agree with Mr. St. John's remarks with all our heart. We went into permanent molding for the reasons he so ably and so plainly comments upon. For instance, in our case it was a matter of either producing better quality locomotive bearings and bronzes, at lower cost, or of getting out of business and letting the railroads drift rapidly to roller bearings and forgings or die castings.

With reference to Mr. Tour's comments, we have cast brass with 10 per cent zinc in permanent molds without meeting any serious trouble from condensation of zinc fumes. Mr. Tour apparently does not know what he really can do in that line with permanent molds until he has tried them out in a willing and intelligent manner.

The empirical formula precisely embodies our statement concerning the desirability of thick walls, and Mr. Tour can check it by assuming a smaller value for T (wall thickness). He will discover, in order to have the first part of the equation balance the second part, which will be the assumed value of T (since the weight and height of the casting are constant, and its pouring temperature is constant—theoretically, at least), that he will have to increase the value of Pr or Rt or t^1, which means that either the casting will have to come out of the mold while too hot, or else he will have to allow the mold to become hotter than the desired maximum of 800 degs. Fahr., thus shortening the life of the mold (paragraph 45 of the paper).

This does not mean that one cannot make a mold with, say, half the wall thickness given by the formula under the above limitations. It simply means that the formula is taking care of these limitations by giving for T the desired heavy wall thickness.

In Mr. Tour's argument as to the accuracy of our statement regarding heat loss from radiation while pouring and during setting period, it seems to us that he brings forward something on specific heat on which we doubt if there is a clear understanding. At least, we would like him to tell us if he actually knows how much more heat it takes to raise the temperature by one degree Fahr. of one cubic inch of cast iron, than it takes to raise the temperature by one degree of one cubic inch of bronze.

Of course, we have taken into consideration the fact that, since the conductivity of iron is different from that of copper, lead or tin, the amount of heat that is required to raise a certain mass of bronze to a certain temperature is not the same as that required to raise the same mass of iron to the same temperature. Assuming that in this latter case the amount of heat is higher, we still have to account for the latent

heat of the molten bronze that is given up at the moment it passes from the liquid to the solid state. We felt that the one compensated the other, still leaving a good deal of heat for which to account.

If anyone is not convinced that there is such a thing as loss of heat from radiation, we suggest that he place his hand as close as possible to the mold while pouring. We feel sure that what will happen will be sufficiently convincing.

A New Type of Inclusion in Cast Iron and Its Relation to Manganese and Silicon Content

By F. J. Cook,* M. I. Mech. E., Birmingham, England.

Abstract

Attention being attracted to inclusions in certain cast irons, forming bright glazy patches, a study of such defects was instigated. It was found that these inclusions, when appearing in castings subjected to steam pressure, caused a tendency for the water to sweat through the glazed areas. The investigation brought out that the glazy areas became apparent when the manganese was within 0.4 per cent of the silicon and increased in intensity as the difference between the two elements became less. Types of castings investigated were diesel cylinder heads, locomotive and marine engine steam cylinders and ammonia compressor cylinders. Bad wearing qualities were not apparent. The author advances the belief that the glazy areas are caused by inclusions in the nature of manganese silicate, although definite proof is not available.

1. The study of metallurgical problems appears to have a tendency to go in cycles. Of late, a great amount of attention and research has been given to manganese, of which not the least in importance have been the investigations made by Dr. Norbury of the British Cast Iron Research Association.[1]

Previously Unnoticed Type of Defect Observed

2. The author recently observed a phenomenon which does not appear to have been recorded by any other worker. This consists of an inclusion in cast iron of bright, glazy patches.

* Vice-President, British Cast Iron Research Association.

[1] Norbury, A. L., "The Influence of Manganese in Cast Iron," *Proceedings*, Inst. of British Foundrymen, vol. 22 (1928-29), pp. 151-176.

Note: This paper was presented and discussed before one of the gray iron sessions at the 1931 convention of the American Foundrymen's Association.

3. The phenomenon under consideration was first met with in some locomotive steam cylinders and consisted of bright, glazy patches which became evident to the naked eye when the cylinder bores were machined. These patches, which varied in size, were not always found in the same relative place, nor adjacent to parts of varying thicknesses. They were usually associated, in fact, with some part of the cylinder barrel remote from the valve-chest side, and where the metal was of even section.

4. The area and degree of glazy inclusion of the affected parts varied from cylinder to cylinder, and in some of the worst cases the areas appeared to be associated with spongy, open-grained metal. Examination with a low-power hand glass showed that the open appearance was due to small crystals of the inclusion having been torn out during machining operations, for the outline of crystal facets were plainly seen in the holes, which gave the spongy appearance.

Further Examples of New Inclusion

5. The foundry in which the phenomenon was first encountered is run on scientific lines with a large chemical laboratory, well equipped and fully staffed, and where daily chemical analyses as well as physical tests of the cylinder-metal cast are taken and

Table 1

Example No.	TC	GC	CC	Si	Mn	S	P	Si-Mn
1	3.3			0.83	0.8	0.08	0.2	+0.03
2	3.27	2.67	0.60	0.92	0.7	0.14	0.33	+0.22
3	3.24	2.2	1.04	0.95	0.79	0.105	0.31	+0.16
4	3.36	2.26	1.1	1.03	0.77	0.130	0.34	+0.26
5	3.48	2.3	1.18	1.12	0.93	0.108	0.36	+0.19
6	3.36	2.33	1.03	1.26	1.05	0.10	0.42	+0.21
7	3.51	2.61	0.9	1.26	1.20	0.083	0.41	+0.06
8	3.45	2.61	0.84	1.26	1.14	0.087	0.32	+0.12
9	3.3	2.29	1.04	1.26	1.38	0.24	0.51	−0.12
10	3.36	2.55	0.81	1.31	1.1	0.105	0.44	+0.21
11	3.27	2.76	0.51	1.26	0.97	0.098	0.37	+0.29
12	3.03	2.36	0.67	1.36	0.98	0.12	0.36	+0.38
13	3.24	2.23	1.01	1.45	1.14	0.10	0.43	+0.31
14	3.45	2.58	0.87	1.45	1.17	0.072	0.48	+0.28
15	3.1			2.01	2.0	0.09	0.46	+0.01

NOTE: Example 1, diesel cylinder head.
Examples 2-10, inclusive, locomotive cylinders.
Examples 11-14, inclusive, marine-engine steam cylinders.
Example 15, ammonia compressor cylinder.

logged under a distinguishing number correspondingly cast on each cylinder. Within a few days of commencing an investigation into the trouble with these locomotive cylinders, the author was called to a similar trouble at another works in connection with some small ammonia compressor cylinders used in refrigerator work.

6. Subsequently, the phenomenon also has been met with in diesel cylinder heads of Continental make, and in marine and general steam-engine cylinders made in five different foundries in Great Britain and on the Continent. Some of the cylinders have been cast vertically, others horizontally.

Silicon-Manganese Relation Apparent Cause

7. The investigation was first commenced by examining individually more than 100 cylinders available and noting which were affected, and the intensity of the trouble. Chemical analyses of the metal showed that the trouble was most intense in castings in which the silicon and manganese were of approximately equal amounts.

8. The analyses of typically bad examples are given in Table 1. This table is arranged, for easy reference, in order of the silicon content of the metal of various classes of castings.

Table 2

Example No.	TC	GC	CC	Si	Mn	S	P	Si-Mn	Remarks
16	3.39	2.48	0.91	1.21	0.74	0.099	0.4	+0.47	Practically clear; 1 small spot.
17	3.3	2.36	0.94	1.31	0.63	0.125	0.27	+0.68	Quite clear.
18	3.42	2.47	0.95	1.31	0.78	0.09	0.39	+0.53	Quite clear.
19	3.39	2.46	0.93	1.36	0.6	0.114	0.29	+0.76	Quite clear.
20	3.42	2.67	0.75	1.4	0.95	0.098	0.56	+0.45	Practically clear; 2 small spots.
21	3.36	2.34	1.02	1.4	0.98	0.073	0.32	+0.42	Practically clear; 3 small spots.
22	3.42	2.45	0.97	1.5	1.0	0.105	0.44	+0.5	Quite clear.
23	3.39	2.48	0.91	1.54	1.07	0.075	0.42	+0.47	Practically clear; 1 small spot.
24	3.33	2.43	0.90	1.36	0.56	0.10	0.27	+0.8	Quite clear.
25				2.03	1.5			+0.53	Quite clear.
26	3.34	2.37	0.97	1.19	0.72	0.115	0.62	+0.47	No trace in bore, but traces found in runner gate.

Note: Examples 16-23, inclusive, locomotive cylinders.
Example 24, marine-engine cylinder.
Example 25, ammonia compressor cylinder.
Example 26, steam-engine cylinder.

9. Included in the table is a column giving the difference between the silicon and manganese contents. Silicon is invariably in excess of manganese in British irons, but the difference very often diminishes as lower and lower silicons come into use.

10. Glazy areas became apparent in every case where the manganese was within 0.4 per cent of the silicon, and the condition increased in intensity as the difference between the two elements became less. The worst case was that of example No. 9 (Table 1), where the manganese is actually higher than the silicon.

Point at Which Defect Becomes Evident

11. Table 2 gives examples indicating the border line. With a difference between the silicon and manganese of 0.45 to 0.47 per cent, there are only occasional bright spots of the inclusion; but with a difference of 0.5 per cent silicon or higher, the phenomenon disappears.

12. In example 26 of Table 2, no sign of glaze was observed in the machined face of the casting, but minute traces were observed under the microscope in a piece of metal from the runner.

13. Examples Nos. 11 and 12 of Table 1, and 24 of Table 2, are of three large marine-engine low-pressure cylinders, weighing approximately 20,000 lbs. each. Nos. 11 and 12 were cast by the time the investigation was commenced.

14. When No. 12 was machined there were evidences of the trouble. At this stage, the author had come to the conclusion that the trouble was associated with a manganese content which was within 0.4 per cent or less of the silicon content.

15. The analysis for No. 11 was found to be such that, if this theory was correct, there should be more glazy inclusion than in No. 12, and when the casting was machined this proved to be the case. In arranging for the metal for No. 24, care was taken to keep the ratio of manganese to silicon outside the danger zone, and the cylinder eventually proved to be free from the trouble.

Procedure Followed to Eliminate Defects

16. In the case of the foundry making the locomotive cylinders, there was a tendency for the manganese content of the metal to vary unduly. The cause of this was traced and rectified, and the trouble disappeared.

17. In the case of the foundry making the ammonia compressor cylinders (example No. 15, Table 1), the mixing of the metal was by rule-of-thumb methods. When commencing to make this type of casting, a composition of about 2 per cent silicon was aimed at and, as this would have a tendency to give rather open-grained metal in the thicker parts of the casting, an addition of ferromanganese was included in the charge to remedy this.

18. The addition of manganese originally added gave about 1.5 per cent in the casting and was successful for some time. Eventually, however, owing to the snow-ball action of the increasing amount of manganese in the scrap and shop returns, a point was reached which brought it within the danger zone. By lowering the manganese content to 0.5 per cent below the silicon content (example 25, Table 2), the trouble was eliminated.

19. So far as the author is aware, no trouble has arisen owing to bad wearing properties of any of the cylinders. However, on the hydraulic test there is a tendency for the water to sweat through the glazed areas, and after the test, brown lines appear around the crystals.

20. It also has been observed that when the cylinders have stood some time, after machining and before hydraulic testing, the glazed areas have a tendency to take on a brown tint.

Probable Cause of Earlier Trouble

21. In 1926 the author was asked to investigate a case of bad local corrosion in the head of a large water-cooled diesel marine-engine piston. He was unable, with any sense of complete self-satisfaction, to arrive at a reasonable cause. However, in the light of the present experience there is every reason to believe it was another example of the phenomenon under review, as the ratio of silicon to manganese was within the danger zone indicated. The complete analysis of the metal was as follows:

Total carbon, per cent	2.39
Combined carbon, per cent	0.76
Graphitic carbon, per cent	1.63
Silicon, per cent	1.25
Manganese, per cent	1.47
Sulphur, per cent	0.044
Phosphorus, per cent	0.066

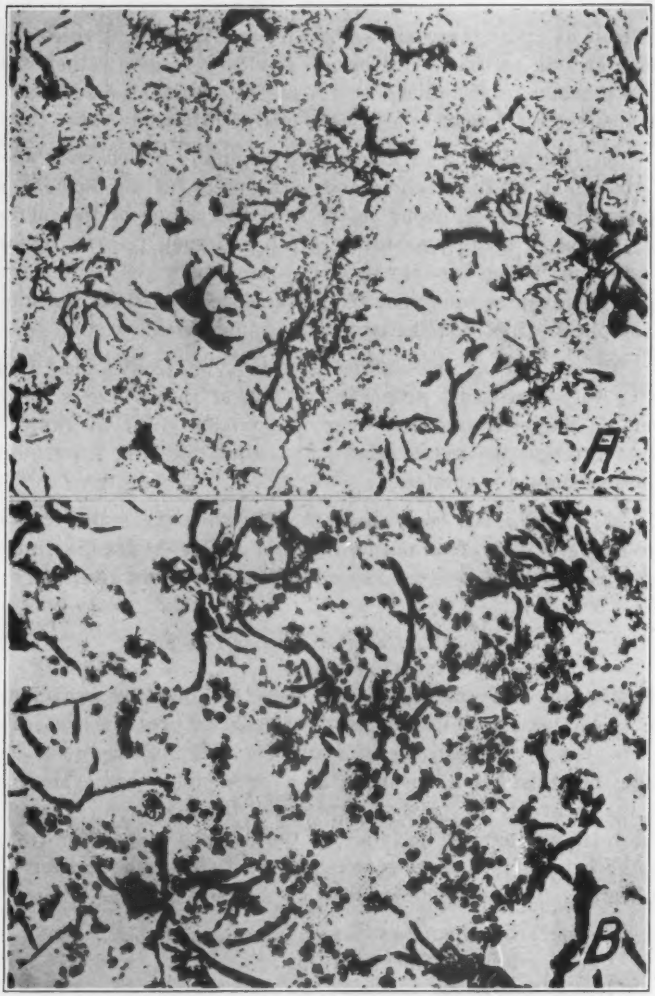

FIG. 1—PHOTOMICROGRAPHS OF SPECIMEN OF GLAZED AREAS DESCRIBED BY AUTHOR. *A:* UNETCHED, X 75. *B:* SAME SPECIMEN AS *A*, UNETCHED, X 200.

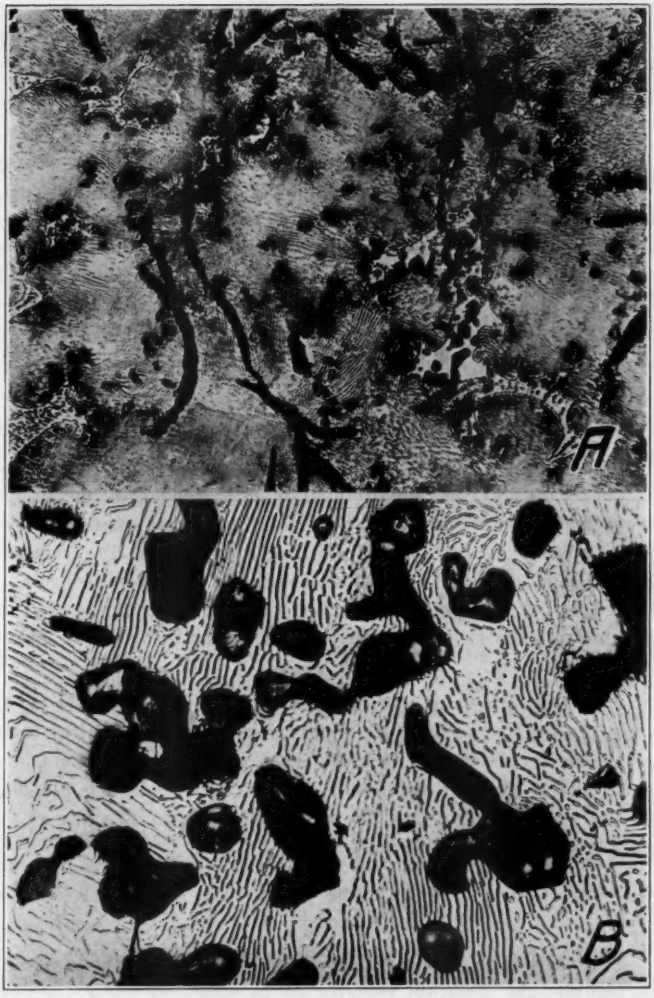

Fig. 2—Photomicrographs of Same Specimens of Glazed Areas As Fig. 1. *A:* Etched with Picric Acid, X 200. *B:* Same Specimen As *A*, Lightly Etched with Picric Acid, X 1000.

22. The low total carbon was intentional, the metal having been produced in a Siemens furnace. It will be seen that the manganese is 0.22 per cent in excess of the silicon and similar to example No. 9 (Table 1), which had proved to have the largest glazed areas.

Structural Appearance of Defect

23. Photomicrographs of glazed areas, taken from example No. 8, Table 1, but which are typical of all, are shown in Figs. 1 and 2. Fig. 1-*A* is at a magnification of 75 diameters, unetched, glazy inclusion being indicated by small half-tone particles. These are associated with relatively fine flake graphite in clusters. This formation of the graphite is an outstanding characteristic of all examples so far examined, which includes many more examples than those given in Tables 1 and 2.

24. Fig. 1-*B* is of one of glazed areas shown in Fig. 1-*A*, at a magnification of 200 diameters, unetched, and shows the clustered graphite more distinctly.

25. Fig. 2-*A*, at 200 diameters, and etched in picric acid, shows clustered graphite and stabilized cementite in the vicinity of the glazy inclusion. This stabilizing effect upon the cementite of not allowing the pro-eutectoid cementite to decompose may be affected by the presence of either sulphur or manganese. The pearlite has been thrown slightly out of focus in order to accentuate the inclusions.

26. Fig. 2-*B*, which has been lightly etched in picric acid, is at a magnification of 1000 diameters and shows the typical formation of the inclusions. The black dots in the dark inclusion areas are holes left by particles having been torn out during polishing, and the white markings in the same areas are mainly due to high lights from the illumination.

Theories as to Cause of Defect

27. Although an alteration in the amount of manganese cures the trouble, the question remains as to what are these inclusions and why and how are they formed? Carl Benedicks and Helge Lofquist, on page 8 of their excellent book on "Non-Metallic Inclusions in Iron and Steel," state that there are two kinds of slag inclusions:

(a) Slag inclusions due to reactions taking place in the molten and solidifying metal which may be called native slag particles (Hubbard in 1911 called them "sonims"—solid non-metallic impurities).

(b) Mechanically admixed slag inclusions and reaction products, respectively, between these and the native slags. These may be termed foreign slag particles.

28. As the inclusions under review appear to be directly connected with the chemical composition, there is reason to consider them as belonging to the first class quoted above, for, if they are due to the second, one would expect to find them in castings irrespective of their composition.

Inclusions Appear To Be Manganese Silicate

29. Seeing that the intensity of the phenomenon appears to be in direct ratio to the silicon and manganese present, and not in any way to the ratio of sulphur and manganese, and also that the shape and color of the inclusions are quite different from those usually associated with manganese sulphide, there is reason for believing that the inclusions are in the nature of maganese silicate.

Constituents of Inclusion Puzzling

30. It is difficult to see, owing to the small amount of sulphur present, that so large an amount of maganese sulphide could be formed. The inclusions do not have either the characteristic angular form of maganese sulphide, nor its dove-gray color. Neither do they resemble inclusions suspected to be double sulphides of iron and manganese.

31. If the glazy areas were manganese sulphide, difficulties in machining would arise, and this certainly does not occur. If the areas were manganese sulphide, why do they not occur in every instance quoted and also in the many cylinders which were found to be quite free? There is plenty of manganese present in each case to satisfy fully the sulphur present in the proportion to form manganese sulphide.

32. Dr. Stead has stated that manganese silicate can be distinguished from manganese sulphide by subjecting the micro-specimens to heat treatment, when manganese sulphide will remain bright and manganese silicate will become dark. On an applica-

tion of this test to the specimen shown in Figs. 1 and 2, glazed particles remained white.

33. Further, it was noted that, when subjecting the specimen to dilute sulphuric acid, bubbles of gas were driven off, which in all probability are H_2S and which is always associated with the presence of manganese sulphide. Sulphur prints also showed distinctly the presence of sulphur.

Attempt to Determine Composition Unsatisfactory

34. An attempt was made to arrive at the composition of the inclusions, by dissolving a piece of the affected metal with the hope that the inclusions would remain while the iron, etc., would be dissolved. The results, however, were not satisfactory. While there was distinct evidence that a slag was present, there was not sufficient residue to make a complete analysis, nor could one be quite sure that the residue consisted of the inclusion.

35. Seeing that the ratio of the manganese to the silicon, and not the manganese to sulphur, has a direct bearing upon the inclusions, may the solution of the problem not be that a manganese silicate is formed and that this has a great affinity for and attracts sulphur, thus forming an alloy containing manganese, silicon and sulphur?

36. Why, under the conditions stated, the phenomenon does arise, is not quite clear. Nevertheless, it is a significant fact that in the very large quantity of cylinders examined—several hundreds—not a single example has been found in which the glazy inclusion is not present when the silicon is not 0.5 per cent or more above the manganese content, and not a single instance where it has occurred when the silicon has been in this proportion.

37. Benedick's second, or "mechanically admixed slag inclusion" definition, is well worth consideration in relation to the present problem.

38. It has been previously stated in this paper that the attempt to separate and analyze the inclusions was not considered satisfactory because it was not certain that the residue actually was the inclusion, and also that the amount obtained was too small—0.3 gram—to make a complete and check chemical analysis.

39. The particulars obtained were as shown in Table 3.

40. The data of Table 3 not only show the substance to be in the nature of a slag but also suggests that it consists of contamination by the furnace or ladle lining.

41. The MnO content of 19.38 per cent is much more than is usually found in a cupola slag, which generally ranges between 4 and 9 per cent and points to the suggestion that the manganese has come from the metal.

42. The 8.9 per cent alumina, 2 per cent lime and 11.25 per cent magnesia gives the impression that it has been obtained from a refractory.

Table 3

	Per cent.
Silica ($Si O_2$)	50.35
Ferrous oxide (Fe O)	7.98
Alumina (Al_2O_3)	8.93
Manganous oxide (Mn O)	19.38
Lime (Ca O)	2.00
Magnesia (Mg O)	11.25
Total	99.89

43. In connection with the question of lining erosion suggested in the foregoing, the author's experience of several years ago with a melting problem may not be without interest in the present case. The metal in question was of a high manganese type, 11 to 18 per cent, and for a special reason it was necessary to oxidize it highly. The melting operation was performed in a cupola and, in order to avoid, as far as possible, carbon pick up from the coke bed, an outside receiver was used.

44. In about half an hour after melting had commenced, the metal would cut through the lining of the pipe leading from the cupola to the receiver. This lining consisted of a firebrick 3 inches thick covered with about 1½ inches of ganister. Trouble also would be experienced with the tapping hole.

45. Both these troubles were eventually obviated by cutting out the whole of the pipe lining after each melt and making it up with a freshly mixed proprietory refractory.

46. It may be that oxidation during melting operation has some effect, for of the 14 cupolas operating in the works in which the cited samples have been made, three of them are known by the author to have a tendency toward excessive oxidation.

ACKNOWLEDGMENT

47. The author's thanks are due and are hereby tendered to L. W. Bolton of the British Cast Iron Research Association, Birmingham, England, for his ready help with the photomicrographs, and to C. Rowley, also of the B. C. I. R. A., for his help in the attempt to separate and analyze the inclusion.

DISCUSSION

ORAL DISCUSSION

D. P. FORBES:[1] Do these inclusions seem to be semi-transparent? If they are, we once observed some similar ones in some malleable castings after annealing; under the microscope they looked like milky glass of some kind. We could focus on the surface very definitely and then seemed to focus at the bottom, and we found them in all sizes, which would contain about 1 per cent silicon and 0.35 per cent manganese.

JOHN SHAW:[2] The analysis mentioned, namely, 1 per cent silicon and 0.35 per cent manganese, is outside Mr. Cook's limits, which are confined to a maximum difference of 0.4 per cent between silicon and manganese. The nearer these two elements approach each other in quantity, the worse the inclusion; that is, so far as Mr. Cook's experience goes.

I have not seen the examples, but in his paper Mr. Cook does make a definite statement that, after the cylinders had been out in the yard, one could go and chalk them out on the outside as if the structure was more or less of that material right through the casting. As to whether or not they were transparent inclusions, I cannot say. They were not transparent clear through, but the surface might have been.

R. M. ALLEN:[3] I am afraid that the essential point made by the

[1] President, Gunite Corporation, Rockford, Ill.
[2] Southsea, England.
[3] Consulting Metallurgist, Bloomfield, N. J.

author in this paper is being entirely overlooked. The question as to the exact nature of the inclusion is a relatively minor matter.

Anyone familiar with the complex silicates that are found in mineralogical combinations will realize that when either an acid, a neutral or a basic combination of aluminum, magnesia and lime is brought together in a molten state with silica, and iron and manganese then are added (there as impurities), if the right combination is used, the corresponding chemical result will be obtained—the elements will go together to form that combination.

This is what has happened in the instances cited by the author of this paper. Incidentally, it might be pointed out that the analysis given in Table 3 is substantially within the limits given by Dana for the compositions of various amphiboles, if we consider the magnesium and calcium as interchangeable; or there are other silicates, as for example the manganese epidote, piedmontite, to which it might be compared. However, because of the complexity of the silicate, it is impossible to identify it unless its crystallographic habits are ascertained.

Discussion of the exact nature of the inclusion is irrelevant. The first thing that matters is that its presence is detrimental to the iron, and second, the cause of its presence.

Undoubtedly the result here is due, as the author intimates, either to conditions in the furnace, the cupola or the ladle where the non-metallic elements are picked up; but here is the point that should not be overlooked: While sometimes it does happen (although it will not necessarily always happen), there is always present a certain ratio between the silicon and the manganese content. In my own experience I have proven it to be the case over and over again, that some relation exists when the silicon and manganese are approximately equal. Especially is this noticeable when dealing with white iron.

I do not know whether there is any foundryman here who is interested in chilled iron, particularly from the wear standpoint; but if he is, he can bank on it that when his silicon and manganese are approximately equal, he has his poorest chill, with the poorest wearing combination possible for the equivalent depth of chill, and that, as the manganese goes substantially either below or above, results will be improved.

There is certainly a critical point here, and I am convinced from some things I have seen in gray iron practice that a similar condition exists here also, that the weakest combination for a given type of iron generally will occur when manganese and silicon are approximately equal. As it is common practice to allow the manganese to run so high, this situation is not often encountered.

The moral is, as Mr. Cook suggests, to keep the manganese down; or, if in the case of chilled iron one is going to work the manganese-controlled chill especially, then one should go far enough above the silicon to keep out of trouble. I believe that is the point, and not the nature of the inclusion, that we should consider in this very interesting paper.

JOHN SHAW: Some may wonder why, in a shop with such good control, the manganese is allowed to wander around in the manner described. It came from a furnace where the silicon and carbon were

carefully taken care of, while the chemists did not think that a few points of manganese mattered. They never tested for manganese in the raw material, although they tested for sulphur, and that was the reason why that particular element was not more nearly controlled. The works were well controlled, but they took no notice that the manganese might have a serious effect by two or three points up or down.

WRITTEN DISCUSSION

DR. A. L. NORBURY:[4] Mr. Cook drew attention in his paper to a matter of considerable practical importance to those engaged in making engineering castings, or, in fact, any sort of castings. The explanation of the slag formation is not yet complete, but it seems quite reasonable to suppose that certain ratios of manganese and silicon will give rise, when oxidized under certain conditions, to certain ratios of manganese and iron oxides and silicates which, by solidifying at different temperatures from other mixtures, will have different viscosities, etc., and will be more or less easily able to free themselves from the solidifying metal.

The analysis of the slag inclusion is interesting and, as Mr. Cook points out, the high manganese content probably was derived chiefly from pig iron, etc. A certain proportion of this manganese had been combined with sulphur, although this was not revealed in the analysis given, since the sulphur was lost during the process of separation of the slag from the metal.

The question of slag inclusions in metal is one of great importance and one which it is very difficult to investigate. Mr. Cook's observations consequently are doubly useful since they suggest lines along which further investigations can be made, in addition to remedying an important defect in the castings referred to.

C. W. PFANNENSCHMIDT:[5] A long time ago we found nearly the same inclusions in diesel cylinders, cast from the cupola. Today they are cast from the electric furnace and there is no such difficulty. I think, therefore, that there is a possibility for manganese silicates, for the analysis of all our cylinders lies within the critical range.

When cast from the cupola, part of the cylinders began to sweat through, but after casting them from the electric furnace there were no difficulties from sweating. I suppose that manganese silicates are destroyed *in statu nascendi* by the CaC_2 slag of the electric furnace.

As to melting in the cupola, I believe in an influence of pig iron. We found in the cupola that the results of the above-mentioned cylinders were

[4] British Cast Iron Research Association, Birmingham, England.
[5] Koln-Holweide, 22 Ferdinand Stuckerstrasse, Germany.

better ones when we used a pig iron with high manganese and silicon content (about 3 per cent manganese and silicon), instead of using one with only a high manganese content.

I believe in an influence of the form of carbon, either as Mn_3C or as mixed crystals of FeMn. What does Mr. Cook think about this? I mean that manganese in a white pig iron is not so active as in a gray iron of the same manganese content, because the first one has all the manganese as Mn_3C.

R. C. GOOD:[6] Mr. Cook is to be congratulated on the presentation of a very interesting paper that describes so briefly and concisely the occurrence of a troublesome inclusion in cast iron. His conclusions seem logical and stimulate considerable thought. While it is to be regretted that more data relative to the melting conditions are omitted, several thoughts about the formation of inclusions, particularly manganese silicates, are pertinent to the paper.

Manganese silicates are formed by the union of manganese oxide and silicon oxide, but the size of silicates and their subsequent removal through their low specific gravity depend to a great extent on the proportions of these two oxides. This condition has been investigated by many research engineers who have studied reactions in the production of steel in the open hearth, and they invariably conclude that the steel with the smallest amount of manganese silicates has been produced with an addition of a manganese silicon alloy so proportioned that the resultant silicate is both large and very fusible.

This analogy can only be made, however, when oxidation of the element occurs such as that found in cupolas occasionally. It is suggested that the glazy patches examined by Mr. Cook were not caused by the silicon-to-manganese ratio in the cast iron, but were caused by oxidation of these elements in such proportions that their oxides combined to form a silicate which coagulated slowly and was trapped in the casting before it could rise to the surface.

A method of introducing both silicon and manganese recently has been presented to cupola operators which limits the oxidation; I refer to silicon and manganese briquets. These can be added to the charge with an anticipated recovery of practically 100 per cent, as the loss due to oxidation is extremely small.

Some time ago a sample of iron that exhibited poor structural characteristics was analyzed chemically and found to contain 0.80 per cent SiO_2 that would have been included with the chemical report for silicon if analyzed in the ordinary way. The results that would be obtained will be appreciated, because the oxide of silicon does not exert any softening or graphitizing tendency; in fact, just the opposite.

Mr. Cook calls our attention, perhaps unintentionally, to the use of manganese in greater amounts in the British Isles than is commonly practiced in this country. The commendable practice of increasing this element improves solidity, fluidity and will inhibit the detrimental influence of high sulphur. Widely separated foundrymen in this country recently

[6] Metallurgical Engineer, Electro Metallurgical Sales Corp., Pittsburgh.

have taken advantage of these factors and in several instances have boosted the manganese to 2 per cent and higher, when 1 per cent was considered objectionable heretofore.

REPLY BY AUTHOR

F. J. COOK: The author is pleased that the paper received so much attention and produced such a good discussion. The remarks of Dr. Norbury relative to slag formations under certain oxidizing conditions are both interesting and instructive, and are in full accord with the opinions held by the author.

It is not clear from Mr. Pfannenschmidt's contribution to the discussion whether he had observed a similar inclusion to that to which attention is called in this paper, which after superheating in an electric furnace had disappeared, or whether, with a composition within the range cited, porosity was met with which was eliminated with electric furnace treatment. In any case, his experience of improvement after superheating is very helpful.

The point regarding the influence of manganese being not so active in white iron as in gray pig iron is one which the author has not experienced, probably due to the fact that he has mostly worked with iron of a gray fracture. However, the query certainly conjures up several lines of thought.

The author cannot accept the suggestion of Mr. Good that the glazy patches were not caused by the silicon-to-manganese ratio but by oxidation of these elements in such proportions that their oxides combined to form a silicate, etc. In such a case it would be possible for the inclusion to form under suitable oxidizing conditions wherever and in any proportions the two elements were present, whereas the glazy inclusions occurred only when the proportion of the two elements were as stated.

Any method of adding silicon and manganese in a cupola mixture so as to insure less risk of oxidation is worth investigation and, if correct, should insure a ready application.

It must not be taken for granted that manganese is employed in British practice in higher quantities than in the United States, for such is not the case. The high contents referred to in the paper were accidental, the reason for which was discovered and remedied.

In reply to Mr. Forbes, the author would not describe the inclusions as being semi-transparent, nor does he think that the inclusions in the malleable example mentioned can be of a similar nature to those illustrated in the paper, since the silicon and manganese are outside the range in which the glazy inclusions have so far been observed.

The author is obliged to Mr. Allen for his very interesting and helpful

remarks. Regarding the bad wearing properties of chilled rolls when the elements silicon and manganese are within the limits to which attention is called, the author has had his attention called (since the paper was written) to the pitting and bad wearing parts of rolls of Asiatic manufacture which are used for crushing sugar cane. The case examined contained 3 per cent of silicon and 3 per cent of manganese and had the glazy inclusions in very well defined areas, each of which were associated with bad pitting and excessive wear.

Effect of Heat on the Permeability of Sea Coal Facing Sands and Core Sand Mixtures

By Walter M. Saunders and Walter M. Saunders, Jr.,
Providence, R. I.

Abstract

An explanation is advanced of the effectiveness of sea coal in facing sands for the purpose of producing smooth castings. On heating test cores of molding sand and sea coal mixtures, and also core sand with binders, the permeability decreases considerably. The proportions of sea coal and molding sand may vary greatly without affecting the reduction of permeability when the mixtures are heated. When sea coal is mixed with molding sand and heated under the conditions of the tests, very little volatile matter is left in the mixtures.

Introduction

1. In a previous paper[1] by the authors, the effect of heat on the permeability of natural molding sands was discussed. On heating molding sands containing moisture, the permeability decreases, irrespective of the class of sand or the location from which it comes. At a fairly low temperature—around 200 degs. Cent.—the permeability is low. Around 300 degs. Cent. it increases, before falling off gradually to a very low figure at 1000 degs. Cent.

2. This break in the curve has been explained by the liberation of steam from the moist sand and by a small amount of gas from the decomposition of the organic matter in the sand.

3. It is the purpose of this paper to describe the effect of a facing mixture containing sea coal on the curves of permeability

[1]Saunders, W. M., and Saunders, W. M., Jr., *Effect of Heat on the Permeability of Natural Molding Sands;* Transactions, A. F. A. (1930), vol. 38, p. 259.

Note: This paper was presented and discussed before one of the sand control sessions at the 1931 convention of the American Foundrymen's Association.

versus temperature of heating. In addition, it was decided to obtain these curves using core sand with binders.

DESCRIPTION OF APPARATUS AND METHODS OF TEST

4. The apparatus described in our previous paper was used. From the molding sands used in the previous investigation, two were chosen for use with sea coal. These sands are called coarse and fine, and are described as follows:

Sand.	Name.	Grain fineness.	Clay substance.	Loss on ignition.
Coarse	Millville gravel	45	15.56%	2.41
Fine	Albany	98	10.80%	1.60

5. The sea coal had the following analysis:

Moisture, per cent.	Volatile matter, per cent.	Ash, per cent.	Fixed-carbon, per cent.
0.82	32.37	9.78	57.03

6. The grain fineness was 148. The distribution on the sieves was as shown in Table 1.

7. Using the modified type of A. F. A. standard ramming apparatus, cores of sand, containing 6, 8, 10, 12 and 14 per cent by weight of sea coal, were made. In all cases the moisture content of these cores of molding sand was held at 6 per cent.

8. It is realized that a fine sand like the Albany sand is not commonly used in mixtures of sea coal for facing. How-

Table 1

SIEVE DISTRIBUTION OF COAL TESTED

Sieve.	Per cent.
20	1.24
30	10.22
40	7.34
50	11.06
70	8.86
100	6.98
140	7.84
200	7.12
270	5.88
Through 270	33.46
	100.00

ever, extreme cases were desired in these experiments, and for this reason it was included.

9. In addition, cores were made of core-sand mixtures actually used in the foundry. Out of several sands tested, three were selected. The proportions of a commercial oil binder and core sand were 1 to 60, 1 to 55, and 1 to 45. These mixtures were called C-4, C-5, and C-6, respectively. The cores were baked in the tube at 200 degs. Cent. (392 degs. Fahr.) for 15 minutes, before use in the permeability tests.

10. The properties of the core sands used were as follows:

	Grain fineness.	Loss on ignition.
C-4	63	2.26
C-5	122	2.13
C-6	180	2.36

11. During the heating of the test cores, permeability readings were obtained at each 50 degs. Cent. (122 degs. Fahr.) interval up to 1000 degs. Cent. (1832 degs. Fahr.). In like manner, on cooling from 1000 degs. Fahr. the permeability was determined. To heat gradually to 1000 degs. Cent. required about three hours, while the operation of cooling to room temperature took about four hours.

12. Determinations were made of the loss on ignition of the dry mixtures of molding sand and sea coal, before the test cores were rammed. At the end of each run, the volatile combustible matter left in the sand was determined, using the same method as in coal.

RESULTS

13. The permeability readings as ordinates, and the temperature as abscissas for heating the cores, are shown in Figs. 1, 2 and 3. No plot is made of the results obtained on cooling from 1000 degs. Cent. (1832 degs. Fahr.) to room temperature. The heating curves for both molding sands without sea coal, are shown as a matter of comparison.

14. The results of the determinations of loss on ignition of the dried molding sands containing sea coal, are summarized in Table 2. Volatile combustible matter left in the molding sands on heating to 1000 degs. Cent. (1832 degs. Fahr.) and cooling to room temperature is shown in Table 3.

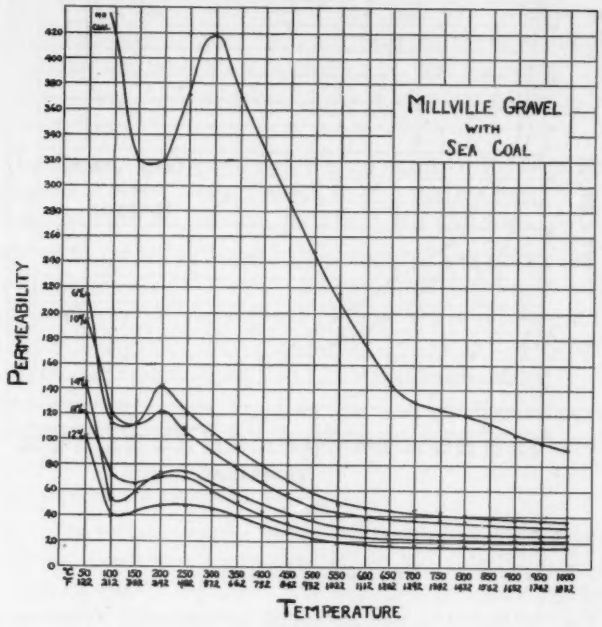
MILLVILLE GRAVEL
WITH
SEA COAL
PERMEABILITY
TEMPERATURE

FIG. 1.

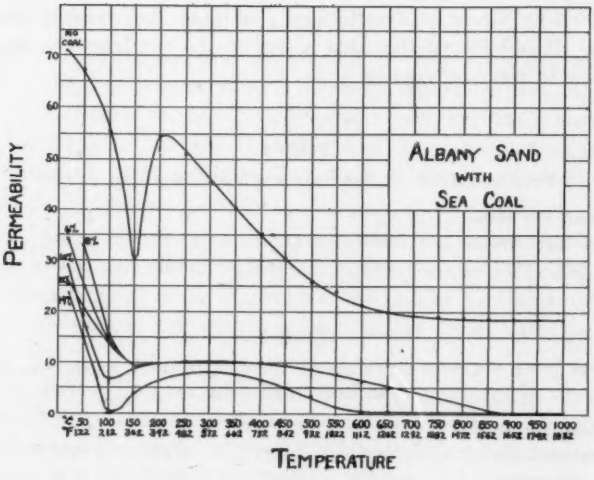
ALBANY SAND
WITH
SEA COAL
PERMEABILITY
TEMPERATURE

FIG. 2.

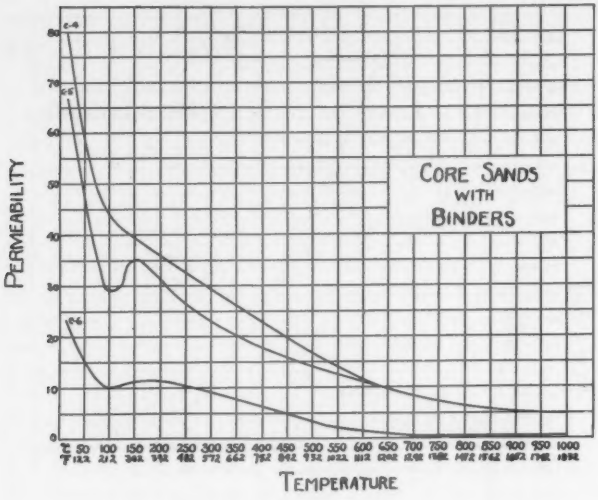

FIG. 3.

DISCUSSION OF RESULTS

15. As expected, the curves of permeability versus temperature are similar to those previously reported. The break in the curve, around 200 degs. Cent., is at a slightly lower temperature for molding sands containing sea coal than for natural molding sands. It is believed that this is due to the gas from the sea coal starting to come off earlier.

Table 2

PER CENT LOSS ON IGNITION ON DRIED MOLDING SANDS.

Sea coal, per cent.....	6	8	10	12	14
Coarse, per cent.....	9 06	11.53	12.24	14.05	15.80
Fine, per cent.....	7.13	8.88	10.48	12.25	13.81

Table 3

PER CENT VOLATILE COMBUSTIBLE LEFT IN MOLDING SANDS HEATED TO 1000 DEGS. CENT.

Sea coal, per cent.....	6	8	10	12	14
Coarse, per cent.....	0.79	0.83	0.92	0.87	0.90
Fine, per cent.....	0.67	0.77	0.65	0.55	0.74

16. Under the conditions of the test, the volatile matter from the coal was distilled off practically in the absence of air. This volatile matter caused considerable back pressure, and in some cases blew the liquid out of the manometer of the permeability apparatus.

17. The sea coal exerted a striking effect on the permeability of the sand at room temperature. Even after the volatile matter had been removed by heating, the effect was still noted.

18. The test cores of core-sand mixtures also follow the same general curves as the above. No break in the curve was expected at 200 to 300 degs. Cent. (392 to 572 degs. Fahr.). The cores were supposedly dry, since they had been heated to 200 degs. Cent. (392 degs. Fahr.) for 15 minutes before use.

19. That there is a break in the curve suggests that some moisture was present. It is believed that this moisture was taken up by the core-sand mixtures, after they were dried, and then cooled to room temperature.

20. The volatile matter left in the sand after heating to 1000 degs. Cent. shows that practically all of the volatile gases have been distilled out of the coal. The loss on ignition of the heated cores was not determined, because it would include the fixed carbon also. For like reason, the volatile matter of the sand and sea-coal mixtures before heating was not determined, as the water chemically combined would be included.

21. It is believed that the results of these tests confirm the theory which has been advanced by many regarding the action of sea coal in facing sands. At different times, various statements have been made that gas from sea coal acted as a cushion between the mold and the molten iron, thus preventing the iron from sticking to the sand.

22. Dr. Moldenke described, in an address before a group of foundrymen, experiments made with facing sands containing sea coal, using a mold with a mica window. The evolution of gas from the coal, and the setting of iron in the mold, was observed in this way.

23. From the permeability readings obtained on heating sea-coal facing sands, it is believed additional light is thrown on what happens when iron is poured into molds faced with sea coal. First, the hot metal dries out a thin skin of molding sand. The

moisture, which is turned into steam, passes through the sand and out of the mold.

24. After this moisture is expelled, the sand, becoming hotter, decreases markedly in permeability, due to the expansion of the grains of sand. At the same time, the volatile matter starts to distill from the sea coal, and the coal around the grains of sand swells.

25. The results of this paper show that this swelling of the coal and expansion of the grains of sand decreases the permeability of the sea-coal sand mixtures to a very low figure. The volatile matter from the coal, therefore, can pass out only along the face of the mold. Meeting the molten metal filling the mold, the gas, or volatile matter, must act as a cushion or film between the sand and metal.

26. That there is a decomposition of the carbon-rich gases of the volatile matter, to "smoke" the surface of the casting, or that a reducing action of these gases on the film of oxide covering the metal takes place, is not denied. The results obtained lead us to believe that a film of carbon-rich gas must be present between the molten iron and the face of the mold.

27. It is well known that the moisture content of molding sand must be kept within limits. Excessive moisture, of course, causes blow holes in the casting. In like manner, the amount of sea coal used in a facing sand must be such that a slow evolution of gas from the coal takes place. Too rapid an evolution, no doubt, would cause a rough surface.

28. While the permeability increased from a low figure on cooling from 1000 degs. Cent. (1832 degs. Fahr.) to room temperature, it was not thought necessary to plot the results. The curves on cooling were smooth and exactly like those previously reported.

CONCLUSIONS

29. From the results of the tests, the following conclusions have been drawn:

(a) Additions of sea coal to natural molding sands result in a decided diminution of permeability at room temperature. This effect is still exerted on heating the sand after the volatile matter has been removed.

(b) The volatile matter in sea coal, together with the swelling of the coal, is responsible for the effectiveness of sea coal in producing a smooth surface on a casting.

(c) Mixtures of molding sand and sea coal used as facing sands may vary considerably in proportions, without changing the behavior of a given sand under heat.

(d) Core sands with binders, like natural molding sands, have progressively lower permeability when heated. The amount of binder used does not materially affect this property.

DISCUSSION

J. M. SAMPSON:[1] Have the authors made any hardness tests of these molds cast with the various percentages of sea coal? The reason I ask this question is because, a good many years ago, there was an article published on the possibility of a series of reactions taking place in which, with an absorption of heat, one would expect an increased amount of hardness with an increased amount of sea coal.

I am wondering if someone here has made those same tests. The author of the article, a Frenchman, in talking about the good effect of sea coal in green sand, said that the sum total of all the chemical reactions that might take place were what are called endothermic reactions; in other words, they would absorb heat.

W. M. SAUNDERS, JR.: In answer to Mr. Sampson's question, we made no castings. This has been a laboratory proposition from the start.

N. A. MOORE:[2] I could not make any statement regarding sea coal, but I know that certain kinds of bonding material will increase the hardness of a casting without having changed the moisture content of the sand.

CHAS. W. BRIGGS:[3] What type of quartz tube was used—silica or fused quartz? At temperatures even as low as 1000 degs. Cent., a quartz tube is very porous and allows gas to escape. Perhaps that accounts for some of the authors' readings being so close together at the lower temperatures.

W. M. SAUNDERS, JR.: It was a fused quartz tube. I do not quite agree with the figure of 1000 degs. Cent. I think that porosity occurs above 1000 degrees.

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[1]Foundry Engineer, General Electric Co., Schenectady, N. Y.
[2]Metallurgist, Piston Ring Co., Muskegon, Mich.
[3]Division of Physical Metallurgy, Naval Research Laboratory, Anacostia, D. C.

CHAS. W. BRIGGS: We have done considerable work with the quartz tube and find that these tubes, even the fused type, would be quite accessible to gases.

W. M. SAUNDERS, JR.: That is rather interesting, but I do not know how one would account for its use in carbon determinations. The temperatures there are 1000 to 1050 degs. Cent.

CHAS. W. BRIGGS: That is all right; there is a sweep of oxygen right straight through.

WALTER L. RANIS:[4] We have had experience in using excess quantities of sea coal in certain facings on light castings where we would get a great number of small, minute surface checks in the casting. They would appear as almost related to the chilling effect that sea coal has on castings. If these were not cast with a sea coal basis, the surface checks would not appear, so the sea coal may have a chilling effect.

CHAIRMAN R. F. HARRINGTON:[5] I wish to suggest something for Mr. Saunders to think about, namely, the question of the fineness of the sea coal. He may already have given some thought to this, and possibly he knows that in the minds of the producers and users of sea coal there is a distinct question as to the best kind of sea coal to use for a particular purpose.

It would seem to me that the authors might well consider the question of the difference in the grinding of sea coal and the point at which the volatile matter is given off. It might affect this permeability reading appreciably, either pushing it up or down on the scale.

C. L. LORIG:[6] There is another factor that has not been considered, namely, that the viscosity of gases decreases with temperature. One might expect more permeability at a lower temperature than at a higher temperature.

W. M. SAUNDERS, JR.: With the 0.5 mm. orifice there is very little gas passing through it. The pressure that is read shows that possibly the volume of the gas that goes through is not more than 50 cu.c.

C. L. LORIG: Nevertheless, the viscosity of that gas is very important as to the amount that will pass through in a given time.

H. H. BLOSJO:[7] At what temperature is that gas measured? The permeability is generally specified as so many cubic centimeters of gas. It will make a difference whether or not one measures the volume of that gas at a high temperature.

W. M. SAUNDERS, JR.: We will grant that, but it is all comparative. We are not positive that this is the correct permeability, but in using the 0.5 millimeter orifice the volume of gas passing is very small, and we believe that the results are comparative only. The orifice is at the base of the permeability outfit, probably two feet before the hot part of the tube is reached. I do not think the temperature there is very high.

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[4]Foundry Superintendent, Union Malleable Iron Co., East Moline, Ill.
[5]Metallurgist, Hunt-Spiller Mfg. Corp., Boston.
[6]Metallurgist, Battelle Memorial Institute, Columbus, Ohio.
[7]Metallurgist, Minneapolis Electric Steel Castings Co., Minneapolis.

Report of Cost Committee Sub-Committee on Inquiries from Consumers of Jobbing Castings

To the Members of the American Foundrymen's Association:

The scope of this committe report attempts to cover information which a buyer of jobbing castings should furnish with a request for prices. On the committee, all four branches of the foundry industry—gray iron, malleable iron, steel and nonferrous castings—have representation. Each committeeman has obtained the experience and suggestions of a large number of representative foundrymen in his particular branch of the industry.

In all, information was received from over two hundred foundrymen, and this report is, therefore, a composite of their views. In addition, the assistance and cooperation of the Gray Iron Institute, the Malleable Iron Research Institute and the Steel Founders' Society of America has been especially helpful.

The production of custom or jobbing castings in large measure is a joint undertaking of the buyer and the seller, inasmuch as it is customary for the buyer to furnish the pattern equipment and, in cases, flasks, core dryers, straightening dies, gages, etc. For this reason, the foundryman, before he can intelligently quote a price on jobbing work, must have a knowledge of the pattern and other equipment which the buyer has or is to furnish, as his costs of production are largely dependent on the character and extent of the equipment with which he will be supplied.

If the requirements of the buyer, for example, are sufficiently large as to make machine production the most economical method of molding, and if a price quotation is made on that basis and the buyer furnishes loose or hand-molding patterns, the foundryman would be unable to get the contemplated production, with the result that his costs would be increased very considerably over his estimate. Conversely, if the buyer's pattern equipment is such as to permit of economical production and he fails to indicate that

Note: This report was presented and discussed before the cost session at the 1931 convention of the American Foundrymen's Association.

fact, he is not likely to receive as favorable a quotation as he would be able to obtain had he given complete pattern description.

Information on numerous other factors of production in addition to pattern equipment—such as specifications, dimension, tolerances, surfaces to be machined, grinding and finishing requirements, etc., of which only the buyer has a knowledge—must be given the seller before he can prepare a dependable estimate, fair to both buyer and seller, of the cost of producing the buyer's requirements.

The dependency of the foundryman on the buyer for full facts and detailed information covering his requirements is therefore apparent, and the closest and fullest cooperation between the two is always in the interest of both. Where the foundryman makes a price on incomplete information on pattern equipment and without knowing the full requirements of the buyer, there is a temptation to play safe and to add a contingency for unknown production factors which the buyer's inquiry fails to state.

An inquiry for jobbing castings, therefore, in the interest of both buyer and producer should be complete in its notations of all essential information. Your committee is of the opinion that the failure of an inquiry to give full information covering pattern equipment, particularly where it is reasonably well designed for economical production, is as often to the disadvantage of the buyer as it is to the seller.

Furthermore, incomplete information, apart from its effect on estimated costs and quoted prices, usually results in delays in production, unnecessary correspondence and misunderstandings.

RECOMMENDATIONS FOR BUYERS OF CASTINGS

Inquiries from buyers of castings, your committee believes, should give the following essential information which is common to gray iron, malleable iron, steel and nonferrous castings:

1—Kind of metal.

2—Sample casting or detailed drawing.

3—If drawing is furnished, the actual weight of the casting should be given. If actual weight is not known, the estimated weight should be given.

4—Number of pieces to be ordered of each pattern, with delivery dates and schedules.

5—Description of available pattern equipment and its condition, indicating

(a) Type of pattern:
Loose (number of patterns and if suitable for mounting on plate).
Gated (number on gate).
Plated (number on plate).
Machine, cope and drag (number on equipment).

(b) Material from which pattern is constructed:
Wood.
Brass.
Aluminum.
White metal.

(c) Number of cores per casting, with kind and type of core boxes:
Number of cores to each box.
Material from which core box is made.
Whether designed for core-blowing machines.
Number and kind of core dryers.

6—If no pattern is available, is foundry to make pattern at customer's expense? If foundry is not to make pattern, will it have the opportunity to suggest how the pattern should be made? If buyer is to furnish flasks the size, type and construction should be given.

7—Drawings should clearly indicate

(a) Important dimensions, dimension tolerances and machined surfaces with amount of finish to be allowed.

(b) Special requirements, such as finish, testing, gaging, special tolerances, disc or special grinding, etc.

(c) Specific locations, if any, for symbol numbers, pattern numbers and trade marks, and whether raised or sunken symbols are preferred.

8—Description of the service or use of the casting. If the castings are to be subjected to pressure, give test to be made and methods of making.

9—State whether pound price or piece price is desired, and f.o.b. point.

10—Indicate any special crating, marking or packing.

In addition to the foregoing information which inquiries for castings should show, and which is considered common to all kinds

of castings, the following information has special application to specific kinds of castings.

Gray Iron

1. Indicate special treatment, if any, such as sandblasting, pickling, annealing, heat treating, normalizing, japanning, painting, enameling, polishing, etc.

Malleable Iron

1. Are castings to receive any special finish, such as for galvanizing, sherardizing, plating, etc.?

2. Are castings to receive special operations, such as straightening, drilling, drifting?

Nonferrous

1. Physical and chemical specifications desired and tolerances permitted.

2. Are there any royalties to be paid by foundry?

3. Are castings to be heat treated, machined or to receive any special treatment such as for plating, etc.?

COMMENTS FROM FOUNDRYMEN

The following comments from individual foundrymen whose cooperation in this study has been very helpful, are of interest.

(a) "We believe an inquiry should be as definite as possible with respect to quantity or pieces actually desired. Often buyers, in their inquiries, specify quantities considerably in excess of the quantity later ordered by them. If, for example, an inquiry specifies 5000 pieces and later an order comes through for 1000 pieces, the price quoted on 5000 is, of course, inadequate to cover the cost of producing in lots of 1000 pieces."

(b) "We believe it would work out more satisfactorily to both the buyer and the producer if the former were to state on his orders the delivery desired. We think it a much better policy for the concern requesting prices to state how much time they can allow for the castings rather than to ask the producer how soon deliveries can be made."

(c) "Many times a buyer will say on his inquiry sheet, 'We to furnish patterns.' This is very misleading. They might furnish one wood pattern, whereas a plate of eight would be the most economical equipment and likely would be what the foundry estimated on. Where the foundryman does not know what equipment will be furnished, he should state that their price is based on a plate of eight patterns, or that with a gate of four patterns the price would be a certain amount additional."

(d) "We always try to ascertain if the casting is to be machined, and what parts are important for fit. This enables us to inspect the castings intelligently and to determine if additional effort and cost have to be made in straightening and finishing operations."

(e) "In addition to specific quantities of different patterns to be ordered, as shown by the inquiry, the buyer should indicate the approximate number of castings purchased per year of a particular pattern number, and also the number of castings of the given pattern usually ordered at one time. The size and frequency of the orders often determines whether it would be advisable to mount loose patterns for machine molding. Also, the information enables the foundry to decide whether to make special rigging which likewise would lower their cost of production. A statement of the approximate annual requirements and of how frequently orders are placed, therefore, often permits the foundry to quote lower prices than they would be warranted in doing without such information."

(f) "In case of inquiries from a source which a foundry has not been previously serving, it is in the interest of both for the buyer to describe any previous difficulty encountered with the castings. Information of this kind is helpful to the foundry in the elimination of trouble. In addition, the foundry often is in a position to make helpful suggestions concerning changes in design to overcome the trouble the consumer previously encountered."

(g) "Many buyers today are asking for piece prices. In such cases, the practice of foundrymen should be to state that the price is based on a certain weight; if, after making the castings, the weight proves different from that given by the buyer, the correct weight will be used in refiguring the piece price."

(h) "Dealings between purchaser and a supplier should be conducted in a spirit of cooperation. This is just as essential as

to have the right organization spirit within an organization. If the purchasing department of the buyer recognizes this spirit, they will be anxious to furnish their prospective supplier with all the detailed information necessary to enable him to arrive at an intelligent estimate."

(i) "A buyer wishing to make a desirable foundry connection is more likely to get a low price if he gives detailed information on pattern equipment and core boxes with probable yearly requirements, together with the exact weight of the castings. An intelligently conducted foundry, which is usually the most satisfactory from the buyer's standpoint, desires to figure close, but does not want to do any more guessing than is necessary."

(j) "We have noticed considerable improvement during the past year or two in the manner in which buyers are sending out their inquiries for quotations, particularly in the motor industry. Only today we received from a large motor company a big inquiry which gives all the information necessary to figure costs intelligently."

Respectfully submitted,

SUB-COMMITTEE ON INQUIRIES FROM CONSUMERS OF JOBBING CASTINGS.

ROBERT E. BELT, *Chairman*
W. J. CORBETT
CHAS. SEELBACH
J. L. WICK, JR.

DISCUSSION

CHAIRMAN A. E. HAGEBOECK:[1] The Cost Committee of the A. F. A. adopted an educational program about ten years ago. We felt at that time that it was desirable to invite the attention of the foundrymen to the advisability of collecting correct cost information.

As the A. F. A., of course, includes the malleable, the gray iron, the steel and the nonferrous castings divisions, we recognize our position as a clearing house for cost information and cost standards, insofar as they can be applied throughout the entire industry.

[1] President, Frank Foundries Corp., Moline, Ill.

Our committee, recognizing that progress has been made in formulating standard cost systems, thinks it is now in order to consider a uniform and definite method of estimating costs. Certainly that is the last of the cycle, and yet it is the most important thing.

The first sub-committee that will report will concern itself with information which a buyer of jobbing castings should furnish when making a request for prices. The members of this sub-committee are as follows:

W. J. Corbett, Fort Pitt Steel Casting Co., Pittsburgh.
Charles Seelbach, Forest City Foundries Co., Cleveland.
James L. Wick, Jr., Falcon Bronze Co., Youngstown, Ohio.
Robert E. Belt, Malleable Iron Research Institute, Cleveland.

I will call on Mr. Belt, chairman of the committee, to present the report.

R. E. BELT:[2] This is a report of the Sub-Committee of the Cost Committee on Inquiries from Consumers of Jobbing Castings.

As the Chairman stated, the personnel of the committee consists of Mr. Corbett, representing the steel branch of the foundry industry; Mr. Seelbach, representing the gray iron branch; Mr. Wick, representing the nonferrous branch; and the speaker, representing the malleable iron branch.

(*Mr. Belt then read the report which appears on pages 449-454, inclusive.*)

CHAS. A. KLAUS[3]: I think the report of this committee is one hundred per cent perfect. Usually we cost accountants do not call a thing perfect very quickly, but I think this report is excellent.

I do not care to comment on this report as a cost accountant, but rather as a man who has managed a foundry for a number of years. One must not expect too much from the buyer. In numerous instances the buyer has to be helped along.

I can cite many cases where a buyer comes to the foundry with some sort of a pattern, perhaps only a blueprint, perhaps a pattern already made up, and he orders some castings. He has no idea how the casting should be made. He does not know the difference between a loose bench job and a job that can be mounted for a squeezer, and it is necessary for the foundry to advise the buyer how it can be made cheapest.

We have always observed the practice of advising the buyer just what would be the best equipment to produce a casting in the cheapest manner. This condition is, of course, something that not every buyer knows, and it is up to the foundryman to advise him accordingly.

These recommendations will be found especially beneficial with squeezer work. Very often a man comes in with an order for five hundred or a thousand pieces and perhaps he wants that size of order three times a year. He does not know that the casting should be rigged up for an aluminum plate or some other way to make it on a squeezer machine—it is up to the foundryman to advise the buyer.

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[2] Secretary-Treasurer, Malleable Iron Research Institute, Cleveland.
[3] Cost Consultant, Gray Iron Institute, Cleveland.

H. P. SPILKER[4]: There is one thing I believe was omitted from the report, and that is to have stated the size flask that a board would require. In other words, four patterns may be put on a board to take a 12 x 16 flask; perhaps six patterns could be put in that same size flask. That would give 50 per cent more capacity in a flask of the same size.

I should say that this little item could be added to the report.

R. E. BELT: We have covered that in a way, probably not adequately, under Item 6. We say, "If buyer is to furnish flasks, the size, type and construction should be given." That is all that is said on the subject of size of flask.

We discussed this point at some length in regard to malleable iron and steel, but I think that in nonferrous work it is very unusual for the buyers to furnish the flask.

CHAIRMAN A. E. HAGEBOECK: I see no objection to adding it in the recommendation. It is just one of those points that might come in mighty handy. I think it a very good suggestion.

R. E. BELT: We had many suggestions for items that we did not include. We had in mind all along not overburdening the buyer with information that he should furnish, which in some cases might be important and in other cases might be very trivial.

Our main objective was to list essential items that inquiries should invariably show. There are specific instances, no doubt, where information in addition to what we have listed would be very necessary in order to permit the foundryman to make an intelligent quotation; but we did not want to fill the report with information that buyers might look upon as a burden to them.

While we did not cover it in the report—because we did not know whether our function embraced that phase of the inquiry or study—we did give some thought to a practical method of merchandising this information, of getting it before the buyer. That is necessary to cash in on the work of this committee.

The study is of no avail unless the information is relayed to the buyer, either through the A.F.A. or through the producer to the buyer. That is a subject to which the proper committee of the A.F.A. outside of this sub-committee could give some careful thought.

In the correspondence which we had with various foundrymen—numbering, all told, in excess of two hundred responses—there were probably as many as six that referred to an improvement, a noticeable improvement, in the last two or three years on the part of buyers in placing known weights or estimated weights of castings on blueprints. I think that is very encouraging.

It probably will be recalled that the A.F.A. initiated a movement in that direction some few years ago. Seemingly, not much headway was made at that time, as it met the opposition of certain of the larger buyers of castings. However, notwithstanding the attitude of a few big

[4] President, Sterrit-Thomas Foundry Co., Pittsburgh.

buyers who opposed that effort, there are instances of improvement in that direction, and it is due largely to the efforts of the A.F.A. in getting that essential information before the buyer.

CHAIRMAN A. E. HAGEBOECK: I believe Mr. Belt's point is very well taken, that this report, representing as it does a great deal of work on the part of this sub-committee, is going to be of very little benefit unless we get it across to the buyer. We will have the committee take this up with the National Association of Purchasing Agents for their cooperation in adopting this as standard practice.

J. L. WICK, JR.:[5] The point of the weight of castings was a point that came up in the discussion of the committee and which I thought was very pertinent. Suppose one does not have the actual weight of the casting; then, working on an estimate, the prospective buyer is given a price per pound. That price per pound, of course, includes the metal cost plus the foundryman's spread.

Suppose, after the order is complete, it is found that the weights are less than the estimate. What will the customer be given? Will he be given credit just for the weight. or for the weight plus the spread?

Suppose it goes the other way. What is the customer going to give the foundryman? He is only going to give him the cost of the metal. Only the metal should be debited to the customer or credited to the foundry. That was one of the comments received from one of the foundrymen which I felt was quite pertinent.

[5] President and General Manager, Falcon Bronze Co., Youngstown, Ohio.

Some Metallurgical Points on Acid Open-Hearth and Electric Steel for Castings

By F. A. Melmoth,* Detroit.

Abstract

Can two steels of equivalent chemical composition, but made by differing processes, possess varied physical characteristics and behavior? This paper suggests lines of thought along which such probabilities may be studied, and gives preliminary data resulting from such an inquiry. The possibility is advanced of considerable further improvement in steel castings, by means of detailed study of steel making, and some interesting suggestions are made on the subject of the influence of non-metallics. The formation, causes and effects of non-metallics in steel are being given special prominence today in all branches of the steel trade. It is realized that the very highest steel standards are unobtainable in the presence of uncontrolled non-metallics, and their presence is deprecated, even when of ultra-microscopic size. The physical properties displayed by steel castings, in conditions of varied heat treatment, are indications of the importance and increasing significance of this operation. Engineering demand is imposing upon the steel founder an ever-increasing necessity for higher standards of performance. The present paper adds emphasis to statements previously made that a step into the alloy field may be regarded as an unjustifiable expense, until such time as the properties latent in high-quality plain-carbon steel are made fully available by scientific manufacture and after-treatment. Steel is the very heart of the steel casting industry, and operation improvement in sand, molding and manipulation should be consistent with continuous research and advancement in this all-controlling element.

* Assistant Manager, Detroit Steel Casting Co.

Note: This paper was presented and discussed before one of the steel sessions at the 1931 convention of the American Foundrymen's Association.

1. It would seem logical to expect that steels of equivalent composition, made in each case in acid-lined furnaces, under slags of fairly comparable types, would possess the same characteristics, irrespective of the method of heat application to the furnace. Over a period of many years, however, the writer has encountered conflicting views on the subject, and from a variety of sources.

2. It is not uncommon, for instance, to meet with the expressed opinion of practical foundry foremen that electric steel gives them much more trouble, particularly stressing the liability of such material to hot-cracking. On the other hand, purchasers of castings often are met with who have a rigid preference for one or the other, but such opinions are very varied.

3. It would appear, therefore, that there may be practical value in an investigation into the relative properties, and the characteristics of behavior, of similar steels made by the two processes.

4. The present paper is an account of work done up to date along these lines at the plant with which the author is connected, and is an attempt to provide data, with micrographic illustrations, referring to the two methods of production.

SCOPE OF INVESTIGATION

5. The plan of operation was as follows:

(a) To compare, physically and microscopically, steels of close chemical composition, given absolutely identical heat-treatment. The object of this step was to disclose not only the relative physical properties when subjected to the usual steel foundry heat-treatment, but to endeavor to show whether, when more exhaustively treated, more nearly to the limit of the material, steel of one type would show any marked superiority. In other words, to bring out any possible variation in the latent capacity of the two materials to respond to more advanced heat treatment.

(b) To show up any variations in the cast structures likely to exert an influence on the practical performance of the two steels in the foundry.

(c) To compare the response of the two steels to heat treatment, from the point of view of time taken to produce equivalent conditions of microstructure, at identical temperatures.

(d) Assuming the confirmation of any suggested variation was arrived at, to study comparative conditions in the furnaces with a view to elucidating the controlling causes.

PROCEDURE FOLLOWED

6. From normally worked charges of steel, six test blocks of electric steel and six of open-hearth steel were cast into dry sand molds of identical size and shape. For these two sets of blocks, it was decided to shake them out after they were solidified, and allow to cool in air. The shape and size of the blocks is shown in Fig. 1.

7. The chemical composition of these test blocks was as shown in Table 1.

8. The schedule of treatments for each block was as shown in Table 2, and the bars were treated in pairs in an electric automatically-controlled furnace, one electric and one open-hearth bar constituting each pair.

Table 1

CHEMICAL COMPOSITION OF TEST BLOCKS EXAMINED

(6 Electric Steel; 6 Open-Hearth Steel)

	C	Si	Mn	P	S
Electric Steel	0.24	0.34	0.77	0.015	0.028
Open-Hearth Steel	0.24	0.28	0.75	0.038	0.035

Table 2

SCHEDULE OF TREATMENTS FOR TEST BLOCKS OF TABLE 1

Pair No.*	Heated, degs. Fahr.	Held, hours	Further treatment.
1	As Cast	....	.....
2	1650	¾	Cooled in air, no draw.
3	1650	4	Cooled in air, no draw.
4	1650	4	Cooled in furnace.
5	1650	¾	Quenched in water, drawn ¾ hour at 1200 degs. Fahr.
6	1650	¾	Quenched in water, drawn ¾ hour at 1000 degs. Fahr.

* Each pair consisting of one electric and one open-hearth bar.

Table 3

PHYSICAL PROPERTIES OF TEST BARS IN TABLE 1 FOLLOWING TREATMENTS OF TABLE 2

(Turned to 0.505 In. Diameter)

Electric Furnace Steel

	Bar Numbers					
	1	2	3	4	5	6
Max. Strength, lbs. per sq. in.	70,000	73,500	72,750	70,000	77,500	85,500
Yield Point, lbs. per sq. in.	40,500	48,750	47,500	41,500	58,500	61,500
% Elongation in 2 in.	19.5	24.0	22.0	31.0	30.0	21.0
% Reduction of Area	19.5	33.4	29.6	44.8	53.3	30.6

Open Hearth Steel

	Bar Numbers					
	1	2	3	4	5	6
Max. Strength, lbs. per sq. in.	71,000	71,500	71,500	70,000	80,000	89,000
Yield Point, lbs. per sq. in.	42,000	44,250	43,250	41,000	59,000	64,000
% Elongation in 2 in.	19.5	31.0	27.5	33.0	21.0	23.0
% Reduction of Area	22.3	48.58	43.4	48.0	63.5	44.85

Table 4

CHEMICAL COMPOSITION OF SECOND SET OF TEST BARS

(6 Electric Steel; 6 Open-Hearth Steel)

	C	Si	Mn	P	S
Electric Steel	0.21	0.35	0.66	0.036	0.035
Open-Hearth Steel	0.27	0.34	0.66	0.033	0.045

Table 5

PHYSICAL PROPERTIES OF TEST BARS IN TABLE 4
FOLLOWING TREATMENTS OF TABLE 2

Electric Furnace Steel

	Bar Numbers					
	1	2	3	4	5	6
Max. Strength, lbs. per sq. in.	65,250	69,750	71,250	65,500	74,250	83,750
Yield Point, lbs. per sq. in.	34,750	45,500	45,000	40,000	55,750	61,750
% Elongation in 2 in.	26.0	33.5	36.0	36.0	30.5	26.0
% Reduction of Area	44.85	57.3	58.3	57.3	61.7	57.5

Open Hearth Steel

	Bar Numbers					
	1	2	3	4	5	6
Max. Strength, lbs. per sq. in.	73,250	78,000	77,500	72,750	85,750	96,250
Yield Point, lbs. per sq. in.	37,500	49,500	50,500	45,750	60,250	69,000
% Elongation in 2 in.	21.5	25.5	27.0	34.0	23.5	19.5
% Reduction of Area	24.08	36.30	35.35	47.72	46.69	41.87

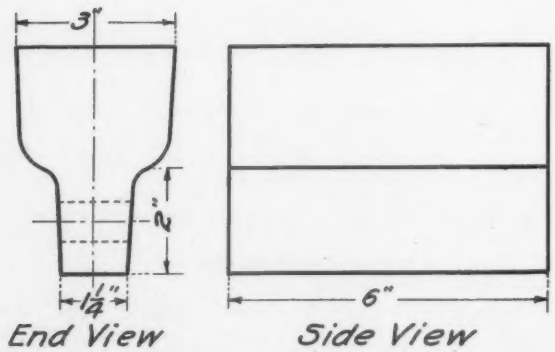

FIG. 1—DIAGRAMMATIC SKETCH OF TEST BLOCKS.

9. The results obtained from bars turned to 0.505 inch diameter are shown in Table 3.

10. As a check on the results of Table 3, six further bars of identical shape and size were cast from each type of steel, and in this case were allowed to cool to atmospheric temperature in the sand before shaking out. The analysis then obtained on the bars was as shown in Table 4.

11. The test results of these six pairs of bars, after heat treatments identical with those which gave the results shown in Table 3, will be observed in Table 5.

12. The test results obtained on all bars are shown in graph form in Figs. 2-6, inclusive.

FORMULA FOR COMPARING QUALITY

13. As some true indication of the comparative quality of the steel in varying conditions was desired which would give full effect to all the factors constituting the tensile test, it was decided to utilize a formula used and recommended by J. KentSmith. This formula, in the writer's opinion, gives an indicative figure which can be accepted as a true reflection of the combined properties shown by the orthodox tensile test, and is as follows:

$$\text{Factor} = \frac{\dfrac{\text{Yield Pt. Lbs. Sq. In.} + \text{Max. Stress Lbs. Sq. In.} \times \text{Elong. \%}}{2}}{100 - \text{Reduction of Area \%}}$$

14. The tensile results worked out on this formula are shown in graph form (Figs. 2-6, inclusive), and the figures are utilized in the detailed consideration of the tests.

DESCRIPTION OF TEST RESULTS ON FIRST SET OF BARS, SERIES *A* AND *B*

Condition 1.

15. In the cast condition, the open-hearth and electric material are practically identical in tensile strength, yield point, elongation and reduction. The quality factors are: Electric 12,650; open-hearth 14,180.

Condition 2.

16. The electric steel would appear to have been influenced

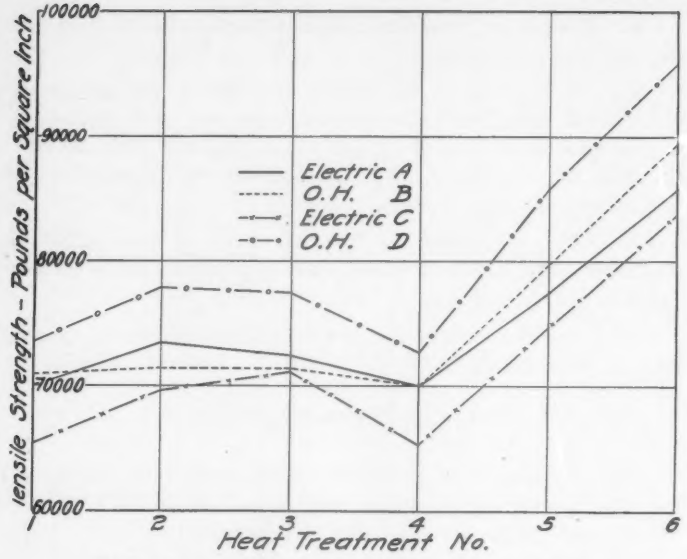

FIG. 2—GRAPH SHOWING TENSILE STRENGTH OF TEST BARS.

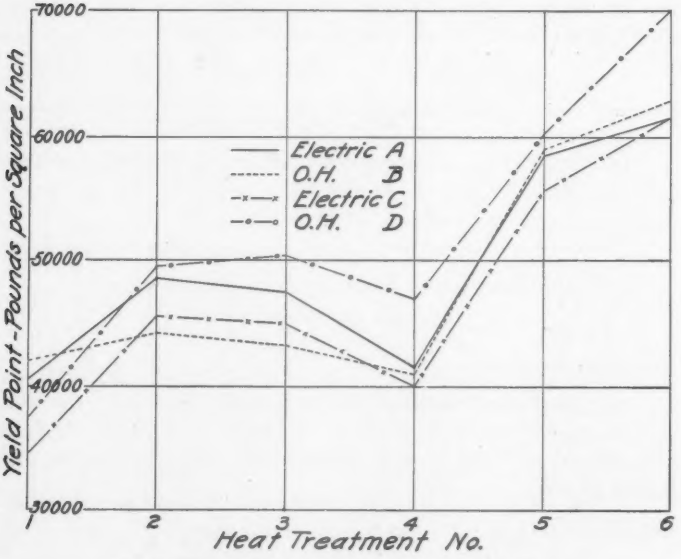

FIG. 3—GRAPH SHOWING YIELD POINT OF TEST BARS.

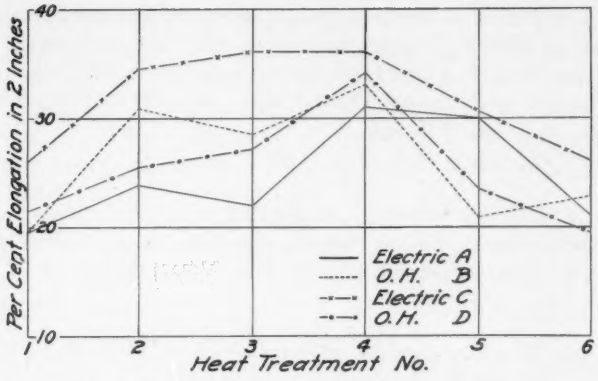

FIG. 4—GRAPH SHOWING ELONGATION OF TEST BARS.

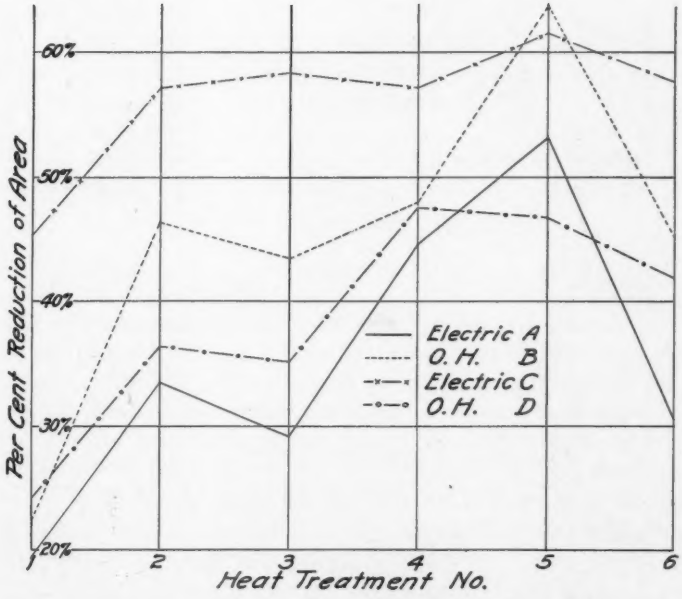

FIG. 5—GRAPH SHOWING REDUCTION OF AREA OF TEST BARS.

by the treatment to a greater extent than the open-hearth material, so far as tensile strength and yield point are concerned. The resulting elongation and reduction of area figures are considerably more improved in the open-hearth steel. Quality factors: Electric 22,020; open-hearth 34,900.

Condition 3.

17. It was unexpected to find that both steels were somewhat adversely affected by the prolonged soaking at 1650 degs. Fahr. The quality factors shown are: Electric 18,660; open-hearth 27,950.

Condition 4.

18. This condition is representative of what might be expected from the usual annealing practice of fairly heavy castings, followed by slow cooling. As might be expected, both tensile strength and yield point are somewhat reduced, but this is accompanied by a very sharp improvement in elongation and reduction of area. Quality factors: Electric 30,946; open-hearth 34,904.

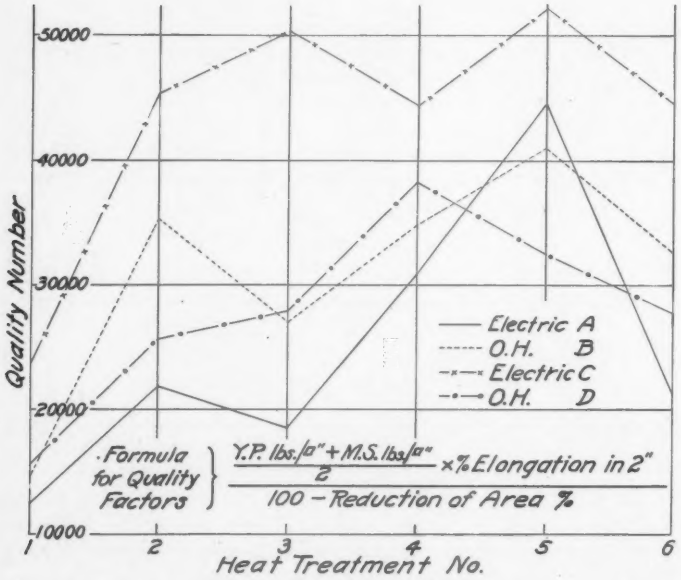

FIG. 6—GRAPH SHOWING QUALITY FACTORS FOR VARIOUS CONDITIONS UNDER WHICH TEST BARS WERE TESTED.

Condition 5.

19. The influence of quenching is very marked on the tensile and yield points of both materials. The fall in elongation in the open-hearth sample badly lowers the quality factor, although it is accompanied by remarkably high reduction of area, namely, 63.5 per cent. Quality factors: Electric 43,683; open-hearth 40,000.

Condition 6.

20. The lower draw temperature has caused an appreciable increase in yield point and maximum strength in both samples. With these higher tenacity figures, the ductility properties have fallen off, particularly in the case of the electric samples. This would indicate that the limit of strength plus reasonable ductility is sooner reached in this electric sample.

21. It also suggests that it is unwise to force a fixed composition to its strength limit of performance by low draw temperatures following a quench, and that a higher carbon content, drawn at a higher temperature, would result in a greater degree of combined strength and ductility. Quality factors: Electric 22,100; open-hearth 31,900.

22. As each pair of these steels is treated together, it would seem justifiable to average the performance of each steel in the six conditions. The average quality factors so obtained are: Electric 25,015; open-hearth 30,639.

EXPERIMENTS TO INVESTIGATE OCCASIONAL ABNORMALITIES IN BEHAVIOR OF ELECTRIC CAST STEELS

23. During the time this experimental work was proceeding, a coincident investigation was being carried out in an attempt to find the controlling causes of certain occasional abnormalities of behavior of electric steel. These deviations from the normal showed themselves in the microstructure of the heat-treated steels as a definite tendency for the ferrite areas to arrange themselves in a straight-line formation, instead of in the usual rounded, evenly-disposed manner. The degree of development of this peculiarity appeared to exert a progressive, deleterious influence on the test results obtainable. A series of photomicrographs showing this condition is illustrated in Fig. 7, *B*, *C*, *D* and *E*.

24. A comparison of these with Figs. 9-*B* and 11-*A* will define these differences of structure quite clearly.

25. Before proceeding to the more detailed discussion of the results of the second set of comparison bars, it would be as well to deal with the inquiry into these abnormalities, as the influence of the inquiry shows itself in the behavior of the second set of bars.

Causes of Abnormal Structure

26. The possible controlling causes of the presence of the abnormal structure might arise from one or more of the following:

(a) Higher temperature of casting in electric steel.

(b) The existence of non-metallic impurities, probably ultra-microscopic, but predisposing the steel to certain formations due to their permanent location.

(c) Some influence of intensely-localized high temperature during the manufacture of the steel, as the result of arc action.

(d) Some variation in working conditions between open-hearth and electric during the manufacture of the charge.

CONCLUSIONS ON ABNORMALITIES

27. So as not to prolong the paper unduly, the writer proposes to state briefly the results of the observations made under each of the above headings, without enlarging on the details.

High Temperature of Casting

28. It was definitely found that, while high temperature of casting would affect the degree of the abnormality, yet its effect could be found at times in samples cast near the end of the pour, when the metal was distinctly cool.

Non-Metallic Impurities.

29. Several charges of electric steel were deliberately held for various periods of time, under a good slag, when ready for tapping. It was considered that this would allow of a more complete coagulation and levitation to the slag of any possible non-metallic material existing in a finely-divided form throughout the steel. Probably the worst case so far recorded of the abnormal structure was obtained in this way, after a holding period of 45 minutes. The test result on this material, after normalizing, was very poor, it being unusually low in elongation and reduction of area.

30. Connected with the consideration of the possible effect of non-metallics is the question of the influence of deoxidizers. This is still being observed, but to date the writer is of opinion that high silicon content or the use of aluminum have a decidedly aggravating effect on the condition. That they are not the cause, however, is indicated by the fact that charges possessing normal silicon content, and in which no aluminum whatever was used, have been recorded as showing the abnormal structure tendency.

Localized High Temperature.

31. It being impossible to eliminate the arc effect, for obvious reasons, no data on this point is available. The fact that it is only on occasional charges that the degree of abnormality is so excessive as to deteriorate quality to a serious extent, would appear to the writer practically to eliminate the idea of its being due primarily to arc effects.

Variation in Working Conditions.

32. To arrive at possible variations of manipulation and conditions in the electric and open-hearth steel manufacture, it is necessary to record each step of the process, as given in paragraphs 33 to 38, inclusive, below.

33. *Materials—Open Hearth*—Steel scrap plus a varying percentage of pig iron. The steel scrap is a mixture of foundry return scrap and foreign scrap, such as forgings, bar ends, etc.

34. *Materials—Electric*—The charge is composed of all steel scrap, this being a mixture of foundry return scrap and bought scrap of the dead-mild, sheet-clipping type.

35. *Condition of Bath When Charge Is Melted — Open Hearth*—Carbon, silicon and manganese are on the high side, owing to use of pig iron. Unless the scrap material contains considerable iron oxide in the form of rust, ore additions are called for to oxidize silicon and manganese and permit the bath to come on to the boil for carbon removal.

36. *Condition of Bath When Charge Is Melted—Electric*—These charges normally melt quite low in carbon, silicon or manganese, unless high-carbon scrap is used. In many cases no ore is called for to bring the carbon down to the desired figure. The bath very often is wild with oxide when molten.

37. *Relative Character of Finishing Period Operations — Open Hearth*—By the addition of controlled quantities of iron ore or limestone, the required reactions to reduce carbon to the desired point are maintained. No excessive oxide at any point is permitted, and during the boiling-down period the temperature of the bath is being built up and slag conditions brought under control. This means that the three factors of temperature, slag condition and carbon content, are all converging to the one point. At this point, which is the desired carbon content, the slag should have become comparatively inactive and the temperature of the metal such as is necessary for tapping.

38. *Relative Character of Finishing Period Operations — Electric*—When low-carbon scrap material only is used, the charge arrives at the melted condition very low in carbon, silicon and manganese, and wild. It is covered by a slag necessarily high in active oxide, and the temperature is comparatively low. The period between this point and pouring is devoted, in good practice, to simultaneously raising the temperature and conditioning the slag. This period is very short when compared with the same one in open-hearth practice.

Three Possibilities in Electric Melting

39. The enormous heat availability of the electric arc is a standing temptation to the quick raising of temperature, and the consequent rapid finishing of the charge after melting and reliance upon deoxidizers to too great an extent, in the effort to compensate for lack of time.

40. A study of these relative conditions suggests three possibilities:

(a) That the carbon content in the open-hearth acts as a continual protective, and that the conditioning of the slag is the result of a mutual effect between slag and the underlying metal.

(b) That the absence of this carbon content in the electric furnace demands bringing a third influence into action, if equally equilibric conditions between slag and metal are to be obtained before tapping; that very commonly this third influence is a deoxidizer such as silicon, which necessarily leaves behind it residual non-metallics which may or may not be eliminated entirely. The silica so produced being extremely fine, it is very unlikely that levitation to the slag occurs to any considerable degree.

(c) That, in the locality of the arc, considerable reduction of silicon takes place from the slag, and that such atomic silicon is very probably quickly oxidized by the iron oxide contained in the molten bath of steel. This would result in the continuous formation of silica in an emulsified form in the steel.

Hypotheses Are Proved

41. It would appear that the best proof of these tentative hypotheses would be a practical trial in which the electric furnace conditions are brought as nearly as possible to open-hearth.

42. Charges were made, therefore, deliberately designed to melt on the hard side, and the carbon content was lowered by the action of the slag. Simultaneously, of course, temperature was raised to the desired point and finishing and tapping carried out in the usual manner. It was found that most charges, melting about 0.35 to 0.40 carbon, required little or no ore, but that a small amount of limestone was adequate to liberate sufficient free iron oxide from the slag to bring the carbon content to the desired 0.15 per cent.

43. It is safe to say that all charges so made and tested showed themselves of considerably superior quality. They were remarkably responsive to heat treatment, and comparatively free from the abnormal structure sometimes previously noted. However, they were not absolutely free from it in all cases.

44. The foregoing description of these trials was necessary owing to the fact that, for the second set of comparison bars, the electric charge was manipulated in the manner suggested by the results of the trials. To the writer, the results are extremely interesting, and continual checks are in progress. Although only the one case is quoted in these comparisons, yet it has been our experience that the results are reasonably consistent, and that the little extra time incurred is fully justified by the intrinsic quality conferred upon the metal.

DESCRIPTION OF TEST RESULTS ON SECOND SET OF BARS (SEE TABLE 5)

45. The heat treatments were carried out exactly to the schedule previously used for the first set of comparisons, and can be referred directly to this schedule.

46. The higher carbon content in the open-hearth bar naturally shows an effect on strength, but the use of the quality factor, as an index of the capacity of the material, really nullifies this for the final consideration.

47. The only variant, as compared with the first set of bars, was that in the case of the second set it was considered advisable, in order to insure identical conditions, to allow the test blocks after casting to cool down to atmospheric temperatures without disturbance.

Condition 1.

48. The slow cooling in sand has lowered the tensile and yield point figures, but materially improved the ductility as shown by elongation and reduction of area. The electric furnace charge is particularly noteworthy, owing to the high reduction of area. Quality factors: Electric 23,550; open-hearth 15,710.

Condition 2.

49. The electric material has responded remarkably quickly to such a simple treatment, and the figures are of a high standard. Quality factors: Electric 45,200; open-hearth 25,500.

Condition 3.

50. The increased soaking period has had little effect, but it is noticeable that the electric sample is somewhat improved. It is of interest to compare this with the previous set of comparison bars, when it will be seen that in this condition the two open-hearth bars are practically identical in quality factor, while the second electric charge possesses a factor nearly three times that of the previous one. Quality factors: Electric 50,200; open-hearth 26,700.

Condition 4.

51. While this treatment has brought out the qualities of the open-hearth material, it is singular to note that the electric steel so treated has lost appreciably in tensile and yield point, without a corresponding improvement in ductility. This suggests that the steel is more easily susceptible to treatment, and that its full properties being attainable in less time, the added time is detrimental rather than beneficial. In other words, it

apparently lends itself more to normalizing than prolonged annealing. Quality factors: Electric 44,550; open-hearth 30,500.

Condition 5.

52. The low carbon of the electric charge, with its comparatively low manganese content, does not lend itself to the attainment of very high tensile figures when quenched and drawn. The yield ratio and reduction of area are high. Quality factors: Electric 51,900; open-hearth 32,800.

Condition 6.

53. As would be expected, the lower draw temperature has resulted in much higher tensile and yield point figures, with some reduction of ductility, as shown by elongation and reduction of area. Quality factors: Electric 44,500; open-hearth 37,700.

54. Averaging the quality factors from this set of bars, we get the following results: Electric 43,317; open-hearth 27,820.

55. Comparing these with the results shown by the first set, they show an increase in the quality factor of electric steel of 18,000 points.

56. As previously stated, all heat-treatments were carried out under automatically-controlled conditions in an electric muffle furnace. Each condition of heat-treatment was simultaneously applied to one bar of each kind of steel, and all times were identical in the two comparisons.

57. It is admitted at once that the whole matter needs carrying considerably farther. So far, our results check off the improvement in test results found in these trials, and we feel that the work involved has repaid itself in the higher intrinsic steel qualities which are built into the resulting castings.

58. It will be of added interest to note that careful observation of difficult castings liable to hot-cracking, over a period of several months, has definitely indicated a considerably less liability to this hot-cracking trouble in the case of the more controlled electric steel.

DESCRIPTION OF MICROSTRUCTURES

59. All of the accompanying photomicrographs (Figs. 7 to 11, inclusive) were taken at 100 diameters magnification, for easy comparison.

First Set of Comparison Bars.

60. The cooling in air after casting has considerably modified the structures shown in Fig. 8, *A* and *B*. It is evident, however, that very great differences exist between the two. The ferrite of the electric sample occurs in a very unusual form, being almost free from the sharply defined acicular arrangement common to low-carbon steels in the "as cast" condition.

61. In Fig. 8, *C* and *D*, the open-hearth steel has responded more completely to the short-time treatment, and has a well-broken-down structure. The rapid cooling in air prevents the coagulation and rounding up of the ferrite masses, but they are very evenly disposed. Fig. 8-*C*, electric steel, possesses areas of more massive ferrite, and there are distinct indications of the formation of lines of ferrite masses.

62. There is little noticeable difference, in Fig. 8, between the steels of *E* and *F* and those of *C* and *D*, with the exception that the ferrite areas in *E* are a little more massive.

63. In Fig. 9, *A* and *B*, the slow cooling has given full play to the enlargement and rounding up of the ferrite areas. Note the tendency of *A*, electric, to form along definite lines. This is the indication of the abnormality referred to in the paper, which, while not so marked on specimens quickly cooled, still exerts pronounced effect on the physical properties.

64. In Fig. 9, *C* and *D* show the typical finely divided structure of quenched and tempered mild steel. It is noticeable that normal ferrite shows as incomplete cell walls in a background of sorbitic pearlite. The abnormal steel (*C*) shows no cell wall formation, but the ferrite is distributed unevenly.

65. In Fig. 9, *E* and *F*, at this magnification (100 diameters), are essentially the same as *C* and *D* of Fig. 9. The cell walls of ferrite in *F* are prominently noticeable, whereas in the abnormal electric steel (*E*) the uneven ferrite arrangement again exists.

Second Set of Comparison Bars.

66. Normal structures of mild steels, sand cooled after solidification, are shown in *A* and *B* of Fig. 10. It is noteworthy that they are practically identical, and that the electric sample (Fig. 10-*A*) is very different from Fig. 8-*A*, previously discussed.

67. In comparing *C* and *D* of Fig. 10, larger ferrite masses

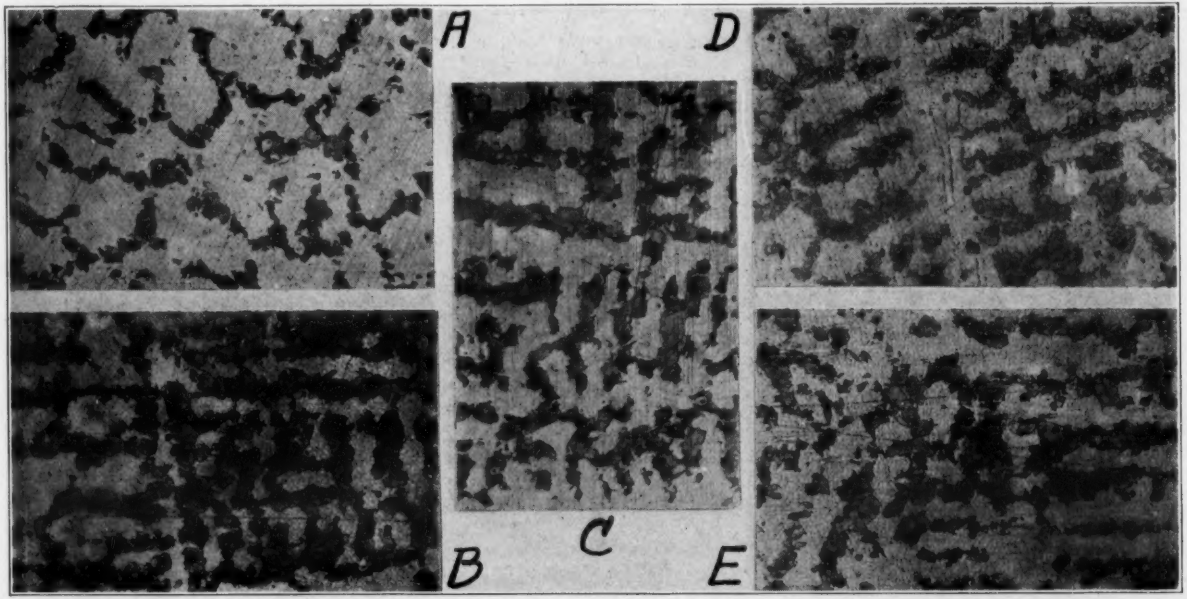

FIG. 7—ANNEALED ELECTRIC CAST STEELS. X 100. HEAT TREATED IN ALL CASES AT 1650 DEGS. FAHR. FOR 1½ HOURS, FURNACE COOLED. CHEMICAL ANALYSIS PRACTICALLY IDENTICAL.

A: NORMAL STRUCTURE. *B, C, D, E:* VARIOUS EXAMPLES OF ABNORMAL STRUCTURES.

FIG. 8—ELECTRIC AND OPEN-HEARTH CAST STEELS. X 100. (SEE TABLE 1.)
ELECTRIC: *A*, AS CAST, COOLED IN AIR; *C*, 1650 DEGS. FAHR. FOR 45 MINUTES, COOLED IN AIR; *E*, 1650 DEGS. FAHR FOR 4 HOURS, COOLED IN AIR.
OPEN-HEARTH: *B*, AS CAST, COOLED IN AIR; *D*, 1650 DEGS. FAHR. FOR 45 MINUTES, COOLED IN AIR; *F*, 1650 DEGS. FAHR. FOR 4 HOURS, COOLED IN AIR.

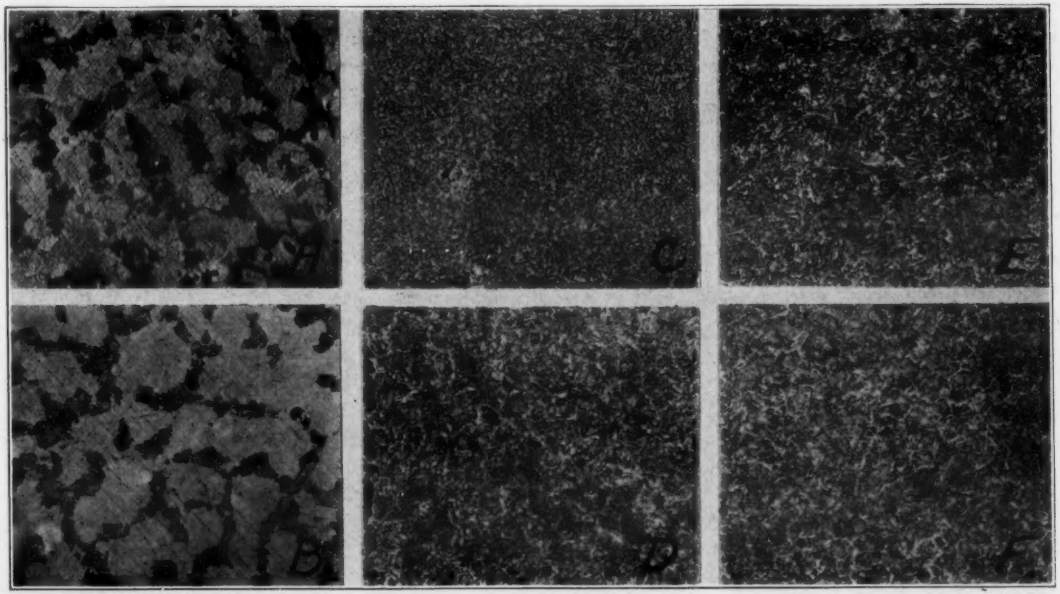

FIG. 9—ELECTRIC AND OPEN-HEARTH CAST STEELS. X 100. (SEE TABLE 1.)

ELECTRIC: *A*, 1650 DEGS. FAHR. FOR 4 HOURS, FURNACE COOLED; *C*, 1650 DEGS. FAHR. FOR 45 MINUTES, WATER QUENCHED, DRAWN 45 MINUTES AT 1200 DEGS. FAHR.; *E*, 1650 DEGS. FAHR. FOR 45 MINUTES, WATER QUENCHED, DRAWN 45 MINUTES AT 1000 DEGS. FAHR.

OPEN-HEARTH: *B*, 1650 DEGS. FAHR. FOR 4 HOURS, FURNACE COOLED; *D*, 1650 DEGS. FAHR. FOR 45 MINUTES, WATER QUENCHED, DRAWN 45 MINUTES AT 1200 DEGS. FAHR.; *F*, 1650 DEGS. FAHR. FOR 45 MINUTES, WATER QUENCHED, DRAWN 45 MINUTES AT 1000 DEGS. FAHR.

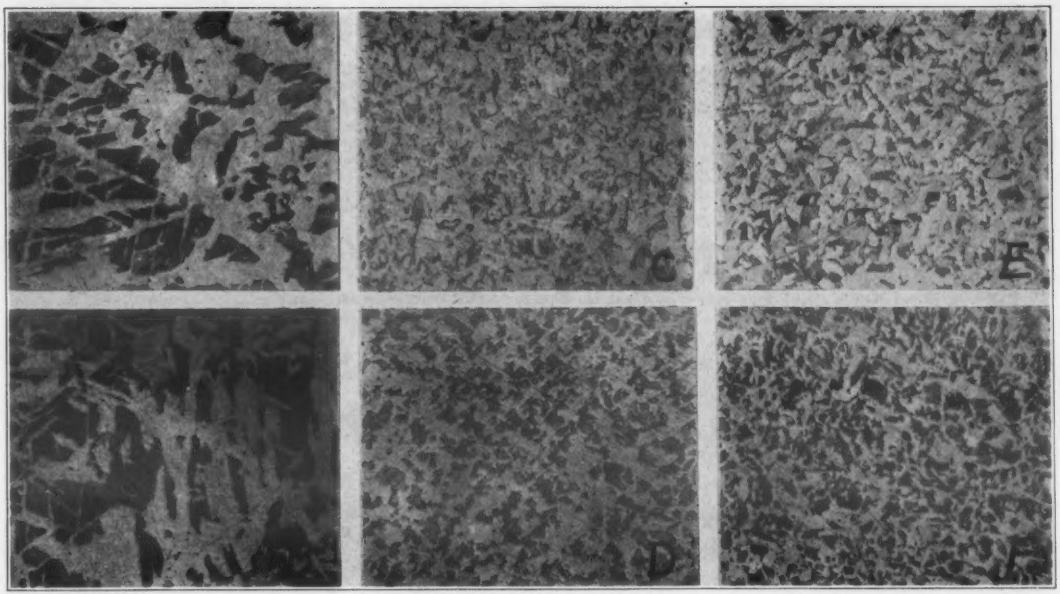

FIG. 10—ELECTRIC AND OPEN-HEARTH CAST STEELS. X 100. (SEE TABLE 4.)

ELECTRIC: *A*, AS CAST, COOLED IN SAND MOLD; *C*, 1650 DEGS. FAHR. FOR 45 MINUTES, COOLED IN AIR; *E*, 1650 DEGS. FAHR. FOR 4 HOURS, COOLED IN AIR.

OPEN-HEARTH: *B*, AS CAST, COOLED IN SAND MOLD; *D*, 1650 DEGS. FAHR. FOR 45 MINUTES, COOLED IN AIR; *F*, 1650 DEGS. FAHR. FOR 4 HOURS, COOLED IN AIR.

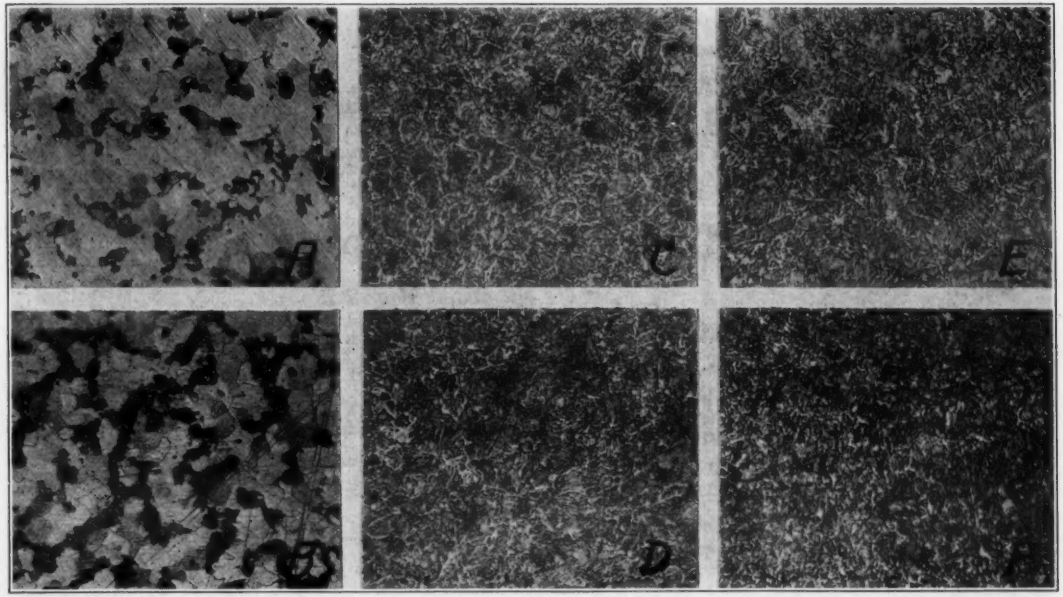

FIG. 11—ELECTRIC AND OPEN-HEARTH CAST STEELS. X 100. (SEE TABLE 4.)

ELECTRIC: *A*, 1650 DEGS. FAHR. FOR 4 HOURS, FURNACE COOLED; *C*, 1650 DEGS. FAHR. FOR 45 MINUTES, WATER QUENCHED, DRAWN 45 MINUTES AT 1200 DEGS. FAHR.; *E*, 1650 DEGS. FAHR. FOR 45 MINUTES, WATER QUENCHED, DRAWN 45 MINUTES AT 1000 DEGS. FAHR.

OPEN-HEARTH: *B*, 1650 DEGS. FAHR. FOR 4 HOURS, FURNACE COOLED; *D*, 1650 DEGS. FAHR. FOR 45 MINUTES, WATER QUENCHED, DRAWN 45 MINUTES AT 1200 DEGS. FAHR.; *F*, 1650 DEGS. FAHR. FOR 45 MINUTES, WATER QUENCHED, DRAWN 45 MINUTES AT 1000 DEGS. FAHR.

in *C*, electric steel, are due to its lower carbon content than *D*, open-hearth. In both cases the distribution is good, and the cast structure has responded very well to the short-time treatment.

68. In Fig. 10, *E* and *C* (both electric steels) show practically no variation in structure. Fig. 10-*F*, open-hearth, does not show by any means so compact an arrangement of ferrite, and the effect of this is noticeable in the tensile strength, which has fallen considerably.

69. In Fig. 11, *A* and *B* show normal annealed structures, slowly cooled. Although the ferrite areas are more continuous in *A*, electric, than in *B*, open-hearth, the tendency to straight-line arrangement of the ferrite (shown so prominently in Fig. 9-*A*) is not evident.

70. In the two hardened and drawn samples of *C* and *D*, in Fig. 11, the free ferrite shows in a normal fashion, as more or less complete cell walls. *C*, electric, should be compared with Fig. 9-*C*, electric, which well indicates the effect of the abnormal condition. The larger amount of free ferrite in Fig. 11-*C* than in Fig. 11-*D* is due to the lower carbon content.

71. Comparing *E* and *F* of Fig. 11, at this magnification (100 diameters), these structures are similar to those of *C* and *D* in Fig. 11, the main difference being in the sorbitic background.

72. The general tendency of the microstructures is to confirm fully the test results obtained. They demonstrate that the abnormal condition in the electric steel carries its effect right through the varied range of treatments. Together with the tensile test, they confirm that, when free from this tendency, almost identical structures exist in both steels.

CONCLUSIONS

73. The writer feels that it is very risky to form definite conclusions on the evidence so far submitted. His main object is to draw attention to the undoubted fact of occasional abnormality in electric steel for casting, with a view to inviting discussion and the experience of fellow members. He believes that this tendency is controllable along the lines suggested, and also considers that we have by no means yet exhausted the possibilities of improving our castings directly through the steel.

74. The cases quoted can be taken as examples only, as very many charges from electric furnaces have been examined. The indications are most distinctly that, although chemically identical, open-hearth and electric steels are not necessarily identical in constitution. So far, the writer's inclination is to place the cause of this as the effect of the existence of non-metallics in the electric steel, unless very carefully produced.

75. This non-metallic material is not necessarily slag in the generally accepted sense of the word, but is more likely to be silica particles of an ultra-microscopic nature. The methods of production, particularly the question of relative speeds, tend toward such a development in the electric acid process.

76. A noticeable feature in many of the check examinations is that, while slow cooling is necessary to develop and disclose the abnormality of structure, yet in such condition the steel almost invariably gives a good tensile test result. The possession of the abnormal tendency, however, shows itself on the test results in the normalized condition, usually as a sharp decrease in the reduction of area capacity.

77. The better behavior of the steel in the mold when free from the peculiarity is a practical manifestation of the value of clean steel to the foundry. The writer is of the opinion that the old view—that any steel just capable of scraping through some arbitrary physical specification is good enough for castings—is due for the scrap-heap.

78. He believes strongly that the incidental barbarisms imposed on the steel by the average sand mold calls for all the fortitude made possible by a high, original, intrinsic steel quality, if the resulting casting is to show the desired service efficiency. In other words, better and cleaner steel is an all-around economy, resulting in better service performance and less trouble in manufacture.

79. As most electric steel for castings is cast into small parts, rarely requiring slow cooling, and also rarely under rigid material specifications, any abnormal tendencies are likely to remain uncovered unless they affect the steel so badly as to sharply reduce its service value.

80. The writer is a firm believer in what is, to him, at any

rate, the fact that the ultimate future of steel castings is entirely dependent upon improvement in quality. By eliminating our variables, by instituting rigid control of every detail, and by a complete understanding (so far as we are able) of the essentials of the product—which each and all mean continued research—we can so demonstrate the possibilities of a casting that new outlets and increased applications will follow quite naturally.

81. It is equally fair to presume that neglect to appreciate the necessity for these things will result in the encouragement of users to try new and improved methods of obtaining their metal products.

82. In the rush of competition—resulting in keen interest, in more production per man or per machine, more and better mechanical handling of material, better control of mold materials, and so on—we ought not to overlook the fact that, even with perfect molds and all that goes to make them, our castings will be just so good as is the steel we put into them.

DISCUSSION

ORAL DISCUSSION

F. A. MELMOTH: The idea has gone through my mind recently that perhaps there is a great deal we could do along strictly metallurgical lines to help the steel foundry get out of some of the difficulties which we must admit are present. In doing so there arises the question of the process by which we make our steel, and its effect, if any, on the behavior of the steel in the molds.

A good many years ago Mr Batty and I were considering the question of basic electric furnaces and the possibilities of dissolved oxides. Various things have happened since then which are convincing me, and Mr. Batty also, I believe, that although we may have been wrong in detail, we were right in principle.

We had no idea what quantity of oxides were present, what their particular functions were, and certainly there were no methods of determination which could enable anyone to state with certainty that our

assumptions were incorrect. All we could do was to produce steel by varying the process in such a fashion as to encourage or discourage amounts of dissolved oxides. Today literature is being published showing that very much larger amounts of dissolved oxides are contained in normal open-hearth steel than ever before was thought possible, yet the steel is perfectly good.

This approaches the point concerning the difference between electric and open-hearth steel. If these inclusions—so very, very small—can have such a pronounced influence, is it not possible that the greater differences in the method of production should leave their mark somewhere on the behavior of that steel?

Rather surprisingly, under normal conditions, they do not appear to leave any very pronounced marks. In other words, acid electric and acid open-hearth steel, produced with equal care, compare reasonably well. However, in making these comparisons we ran into peculiarities.

All these abnormalities are by no means absolutely constant, but they are sufficiently significant to make one think. I believe, and believe strongly, that this is the line along which the metallurgist can do the most useful work. He can do a great deal more good today by making safer steel, stronger steel, at the time of solidification, than he can by the addition of indiscriminate amounts of alloy to produce some new, patent, fancy-name steel.

These peculiarities in electric steel are definitely associated with a change of behavior in the foundry. I feel no doubt in making this statement, although I am checking those effects, and I think that quite a number of other people are doing the same.

In our own foundry there was a firmly convinced opinion that if electric steel were taken into the foundry and cast into heavy castings with a pronounced liability to cracking, it would surely crack. That is not the case. When electric steel is behaving in such fashion it is a definite indication of some abnormality, or of the use of too high a temperature.

It is easy to see from the shape of the structures shown by the photomicrographs of abnormal types, that such acid steel would be more liable to the tendency to cracking.

I believe, as time goes on, that the sources of these abnormalities will be found and corrected. In any case, the steel being produced possessing these abnormal structures is capable of passing easily the normal standards.

CHAIRMAN JOHN HOWE HALL:[1] As I understand it, the point raised is the occasional acid electric furnace heat or even basic electric furnace heat which, instead of giving good elongation and reduction of area, gives poor elongation and reduction of area and refuses to respond to heat treatment for a cure of the trouble.

The paper also details work which has been carried out, and still is being carried out, involving a change in acid electric furnace practice designed to prevent the occurrence of these abnormalities. I do not

[1] Technical Assistant to President, Taylor-Wharton Iron & Steel Co., High Bridge, N. J.

suppose there is a man here who has ever run an electric furnace who has not had some of these abnormal heats. It is an exceedingly important and an exceedingly live question.

R. A. BULL:[2] What does the author think is the probable difference in the average temperature of the open-hearth steel, the results of which are shown, and the temperature of the electric steel?

I believe we will agree that this matter of temperature probably has a very important influence on the physical properties of the metal and its responsiveness to heat treatment after it is cast. The extent to which the metal is affected by a relatively high temperature in the bath, or as poured, of course is extremely difficult to ascertain. We know that high temperature has certain difficulties following in its wake, such as shrinkage cracks and tendency to porosity, for very logical reasons; but probably many of us feel that the disadvantages coming from a very high temperature, which are so easily obtainable in the electric furnace, are considerable.

We would like to know more than we do now about those disadvantages. It may be that the difference in temperature, if in Mr. Melmoth's opinion it was appreciable, might account for at least a portion of those differences in physical behavior when the compositions were fairly comparable.

Mr. Melmoth probably chose as convenient a method as he might have been able to get, in the use of the merit index which he applied and which was recommended to him by Mr. KentSmith, whom many of us know very favorably. At the same time, that merit index or quality factor—whichever one chooses to call it—does not seem to be entirely satisfactory for castings.

I have played with this index for the purpose of comparing cast steels a good deal more than I have for any other variety of steels, and I find that it does not seem to fit certain conditions. At the same time, I do not know of any other factor that would serve the purpose quite so well.

Quality factors or merit indexes have been sprung on the technical world since about 1850, when Wooler first proposed one, and I do not know how many there are existing today, although I know of at least twelve. Professor Stoughton and Professor Harvey, at the 1930 convention of the A. S. T. M., probably enumerated more such factors than have been listed in any other one paper, and they made very interesting comparisons of quite a number of forged and rolled alloy steels, just to indicate to those who were interested how these various quality factors would work out. The presentation of that paper provoked considerable discussion, the result of which seemed to be that there was no satisfactory factor that could be applied generally.

It might be interesting to look at two results among a number which I have worked out from time to time to find a merit factor or quality factor which seemingly would suit the purpose of such a general comparison as Mr. Melmoth has attempted to make. The results from two actual test bars are as follows:

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[2] Director, Electric Steel Founders' Research Group, Chicago.

Yield Point, lbs.	Tensile Strength, lbs.	Elongation, per cent.	Reduction of Area, per cent.
42,650	71,900	31.5	53.9
49,470	85,310	24.0	46.8

The quality factor which Mr. Melmoth has applied, and which was developed, I believe, by Cutter and presented before the A. S. S. T. in 1920, gives interesting values for these two bars. The first one figures out 39,051. I am not going to ask anyone to express or commit himself, but everyone can figure out in his own mind, if the value for the first bar is 39,051, what the value for the second bar probably is, with appreciably higher ultimate strength and yield point, and lower elongation and reduction.

Actually, the second bar figures 30,401. In other words, if the first heat is worth 39, the second is worth but 30.

That does not seem to me to be the right relationship, and it indicates to me, at least for these particular combinations of physical properties, that the formula does not fit. It establishes a ratio on the order of six to eight.

Thus, we might say, if the second steel is worth six cents a pound, that the first steel ought to be worth eight cents a pound. I do not believe that would be reasonable, for ordinary structural purposes, and I am not prepared to say what those two sets of figures are worth, relatively, but I do not think there is any such difference in them as is indicated by that factor.

What I have said is not a criticism of Mr. Melmoth's attempt to use some satisfactory basis for comparison. It merely illustrates the difficulty that has prevailed for a long time, and discovered by many, to find some satisfactory basis of comparison. Obviously, when we are trying to make a comparison between a number of bars made by two different processes, we must find some measure. All of this, of course, is aside from the salient points in the paper, and applies to working out the details.

I do not know to what extent this matter of temperature may be a factor. Mr. Melmoth probably could enlighten us considerably on this if he can tell from his own observation the approximate difference in his working temperatures.

In this connection, I have found it very hard to try to actually determine temperatures by means of optical pyrometers, because it is so difficult to maintain all the factors that enter into the determination of the temperatures in that way.

F. A. MELMOTH: Major Bull certainly has brought out one point on which I would like a great deal more information. I have had no experience with optical pyrometers which leads me to believe their results can be trusted under the varying conditions of the steel foundry.

The experiments have been worked out under as nearly practical conditions as possible. I have a feeling that we are likely to be accused of being just scientists, and as such not necessarily having any intimate

contact with the foundry. Therefore, these experiments were carried on under foundry conditions with an attempt made to hold temperatures to foundry limits.

That is a weak situation, but the only one I could take up. I could not trust an optical pyrometer under these conditions, in addition to which it would not show me the actual temperature to which the metal was subjected in the furnace, a point which is of considerable importance.

It does not necessarily follow that we have told the whole story when we say that we have tapped our heat at 3000 degs. Fahr. It may have been worked at 3500 degs. Fahr., which may have marked or imprinted it with some special condition. There is no optical pyrometer that can tell us that, except through the relation of bath temperature to the brick-work temperature, which is not reliable at all.

In regard to the formula, like every formula for its purpose, it is not perfect. I believe Brinell did a great deal of work along similar lines on one occasion in connection with formulas for sound steel. It is fully realized that no one formula so far evolved will meet all cases.

All I could hope to do, and I know Major Bull saw this point, was to get something that would show a fairly comparative idea of the values of the tests. It could, if necessary, be struck out entirely from the paper without making any difference as to the basic underlying idea, but it occurred to me that it would be rather interesting to show up in a fairly comparative way the relative qualities of the bars.

In my introduction I do not think I said a word about any ideas I had as to what was underlying this peculiarity. I had hoped that someone would draw that out or, perhaps, otherwise give me something to talk about; but here is a point which I think is worthy of consideration.

Every electric furnace man I have spoken to for years is more proud of the fact that he can take a heat out in an hour and a quarter than he is of the fact that when he gets his steel it behaves absolutely perfectly.

Among my friends in Sheffield district there are a number of older men who have been in the steel trade for (in some cases) as much as fifty years. Most of these men are using steel, and if I wish to know anything about steel I would rather go to the man who uses it than to the man who makes it.

The remarks of these men to me are, in effect, along these lines: "You metallurgists may be getting out in five hours an open-hearth heat which used to take you thirteen hours; you may have succeeded in making your open-hearth heats with fifteen per cent pig iron when we used to use sixty per cent; you may have electric furnaces which give you a wonderful exhibition of mechanical skill, and so on; but you can't make steel like they used to make it."

That seemed to me rather upsetting, because if there is one thing the steel makers claim, it is that they have progressed. It would go down bitterly with the elite of the steel-making world to be told that steel is not as good today as it was twenty-five years ago. Yet certain old file-

makers insist that with the steel made under modern conditions they cannot get the results in producing files or turning out cutting tools, that they got out of steel made under the old conditions. There is a bait thrown down for someone to attack.

I believe that we can sacrifice too much to speed. I believe that we can take an electric furnace and push into it immense quantities of energy and, when we have finished, we will pay a bigger price in our foundry, and probably in the product outside, than the amount which has been saved by gaining that time on the electric furnace.

This is not an excuse for sluggishness or sitting down smoking while the furnace does its own work, but I believe we can go too far with the question of speed. There are certain readjustments, certain reactions, and more particularly physical readjustments, which have to take place and which are outside our control. There is nothing much we can do to speed up those readjustments.

Time is the controlling factor. We deliberately cut that out and make it a boast that we have cut it out. In other words, we have secured economy along one line, but we probably have obtained extreme wastefulness along another line.

The question of non-metallics is getting a tremendous amount of attention today. It is hardly necessary to say much about that; anyone can take up a technical journal and find a lot of really useful information about non-metallics. A large amount of work is being done along these lines in this country, and a great deal of interesting material is coming out of those investigations.

Do you not think the question of non-metallics of a sub-microscopic nature may be the basis for this particular formation? Mr. Batty has advanced that idea on more than one occasion, and I am inclined to agree with him, for this reason:

In this paper mention will be found of one charge where we applied all those apparently wizard-like things which we steel makers are supposed to do, where we waved the magic wand over it and said: "That is a perfect heat. Now hold it for three-quarters of an hour and it will be still more than the perfect heat, because all of this time effect will thus be permitted to take place; all of this readjustment must take place in such a period of time."

That was the worst heat we made in any of our trials. We had deliberately overshot the economic mark of the proper usage of time and we encouraged certain reactions to take place in the slag, which became more or less encyclic and encouraged the production of particles of a different nature from those normal to such steel, sufficient in number and effect to produce bad tests—and I mean bad tests; that heat gave a really bad test.

The other side of the picture is that we should not go too far in the direction of speeding up.

CHAIRMAN JOHN HOWE HALL: It seems to me that this whole question of abnormal heats is due to the fact that iron itself is a very sensitive element. The paper deals with abnormal heats made in the acid electric furnace, but we have just that same type of abnormal heat in any

steel-making process I have ever had experience with—and I have had experience with them all.

When I was first in the game, in 1904 at the old Bethlehem Steel Works, we made steel under the John Fritz tradition, which was a good deal like the Sheffield tradition. We made acid open-hearth steel slowly and we made it almost entirely for forgings that had to meet government specification. We had to make all kinds of high-grade gun hoops, gun tubes, shafting and other things to government specifications, and we had a lot of transverse tests to meet on gun hoops and gun tubes.

About 1906 they brought a man from Pittsburgh and put him in charge of the open-hearth department. In six weeks he doubled production; in about another six weeks his steel worked up to the testing laboratory, and when it came to those transverse tests, if one wanted to see abnormal steel, that was it!

He made acid open-hearth steel in about half the time they had previously required, brought his bath down to analysis still wild with ore in the slag, did not allow the carbon elimination rate to slack off toward the end of the heat but ran his heats down fast, killed them with silicon, and tapped them out. Steel made in that fashion was oxidized and of poor quality, and gave thoroughly abnormal tests.

I had a queer experience with bottom-blown converter steel during the war, which gave me exactly the same impression, namely, that the element iron must be protected from oxidation. We had a small bottom-blown converter which we had always run according to Swedish practice, our charge to the converter containing from two to three percent manganese. So long as we followed that practice, we got cast steel with excellent physical properties.

During the war, when manganese was so expensive, we became economical and would not put manganese into our charge any more, but tried to blow metal containing 1.5 to 2.0 per cent silicon, with manganese under 0.50 per cent. I suppose I made forty blows of steel that way to meet army specifications, and it is almost no exaggeration to say that I lost every heat. The elongation and reduction of area were very low and no amount of heat treatment would bring them up.

We returned to the Swedish method with manganese in the converter, and we eliminated ninety per cent of our trouble on the day we made the change. As far as I can see, the only useful function of the manganese was to protect the iron from oxidation during the blow.

I have had the same experience with tropenas steel. Some of our tropenas metal has this peculiar structure that Mr. Melmoth shows in his pictures; instead of having the uniformly disposed ferrite and pearlite, it is disposed in lines. This is shown particularly, in Mr. Melmoth's paper, in *B* and *C* of Fig. 7, and in *E* of Fig. 7, for that matter, where the ferrite is disposed in lines. If steel like that is obtained, one can feel fairly sure that a large proportion of the abnormal-looking metal will not exhibit good physical properties, and we get it in occasional heats of tropenas steel made on an acid lining.

A few years ago, with the help of Dr. Lucas, I tackled the job of trying to work out the reason for the occurrence of these abnormal heats.

We tried to tie the trouble up to pouring temperature, and found we could not do it; we tried to tie it up to the amount of aluminum addition, and apparently we could not do that either.

Then we tried to find the answer in the length of time after the heat was turned down before we poured the test bars, and there we got a partial tie-up. In a great many cases a test bar poured within three minutes of the time the converter was turned down would have very poor elongation and reduction of area and would generally show this abnormal structure, whereas a bar poured fifteen or twenty minutes later would give first-rate tests. That might be explained partly by temperature and partly by the fact that the steel might clear itself of inclusions in that time. However, it did not work every time; sometimes the steel would have good properties when poured early, and sometimes it would not.

Although we did not get anywhere—we finally gave up the attempt—I do feel that the occurrence of abnormal heats is somehow associated with the fact that the element iron is exceedingly prone to oxidation, and that when a heat is hurried in the furnace, when it is melted down dead low in carbon, the iron is seriously over-oxidized and, in spite of one's best efforts, the damage can never be completely undone. I have heard metallurgists claim that a heat made in a hurry out of all scrap, melted down dead low in carbon, could never be restored.

GEO. BATTY:[3] It is not very interesting for me to talk to Mr. Melmoth when we are in agreement, but we are so very much in agreement at this time that I can only try to amplify some of the things he has said.

We have had a good deal of correspondence on various matters, and recently we have been dealing with this matter of the peculiar abnormal or subnormal behavior of electric steels as compared with open-hearth steels of equal or similar composition, as revealed by conventional analysis. We are definitely agreed that this time factor—that is, a proper apportionment of time—is a significant one in the making of good electric-furnace steel by the acid process, just as it is also by the basic-electric process.

In the course of our correspondence we have suggested to each other (the idea is not at all novel) that this peculiarity of behavior exhibited by some of these acid electric steels may be due to the influence of sub-microscopic non-metallic particles as well as the particles of non-metallics that are visible under the microscope.

Recently, when I was preparing a paper for the A. S. S. T. on the making of acid-electric steel, I differentiated between steel making and steel melting. Unfortunately, I stated that most of the material that was put into acid electric castings was merely electric-melted steel.

I think I must withdraw that statement. Much of the material—not most if it, but much of it—is merely electric-melted steel and not electric-made steel.

We must remember that in the acid-electric process our first effect of heat application in the liquefaction of the charge is to pollute that charge with non-metallics by the oxidation of silicon and manganese. In oreing

[3] Technical Director, Steel Castings Development Bureau, Philadelphia.

down—I personally insist that the heat must be seen to boil, although not necessarily violently—we have a sufficient amount of oxide of iron present to insure the almost complete levitation of the initially formed non-metallics.

However, if one will look into Herty's work with regard to the FeO carbon equilibrium diagrams, it will be seen that, as the carbon is decreased in the metal, the ferrous oxide content increases in order to promote the elimination of carbon. When we come to the time when the "finals" of silicon and manganese normally are added to that heat of metal, we so disturb that FeO equilibrium with carbon, plus the added elements, that we are bound to get some non-metallic formation.

The fineness of subdivision of those non-metallics affects the speed of levitation, and there is the second effect that Mr. Melmoth mentioned: The precipitation of silicon or reduction of silicon from the slag, which we assume is atomic, forms molecular compounds and probably is submicroscopic.

Mr. Melmoth suggested to me that we should use the term "colloidal non-metallics" in the liquid steel as affecting the crystalline arrangement of the solidified steel. I believe we must visualize those finely divided non-metallics as latent foci or nuclei on which the metal will subsequently crystallize, and in any subsequent heat treatment it is logical to assume that they will form focal points. Thus, we have a persistence of the cast structure promoted by non-metallics; hence the failure of certain steels to respond adequately to heat treatment.

In respect to this speed of production of electric steel, I came across some of Geoffrey Chaucer's words that struck me as being particularly appropriate: "He hasteth wel that wysely can abyde." It surely is true that in the making of acid-electric steel, as in the making of steel by other processes, there comes a time when we must abide—just wait a while—and let the proper time element enter into our process.

Another factor that is bound, I believe, to affect adversely electric steel as compared with open-hearth steel, is the fact that, as a rule, the electric furnace is so disposed that there is a certain amount of "raw" bank to pour over. I consider it good practice, in making electric steel, to tilt the furnace, during the later stages of making a heat, so as to bring the slag level to the taphole or spout, thereby decreasing the area of "unwashed" bank over which the steel must pass in transference from furnace to ladle.

Then the ladle practice in electric-furnace foundries is not as clean nor as good, generally speaking, as it is in the open-hearth practice, and there we get into the pollution of the steel as well as the pollution that has occurred by the precipitation of silicon from the slag.

On the question of temperature, I believe we must go still further into the realm of conjecture, because the heat application in the electric furnace is intensely local, and it is intensely high as compared with the application of heat in the production of open-hearth steel.

A very significant thing occurred in my work. In one case where open-hearth heats by the acid process were produced rapidly, the results were poor compared with results of the same plant when open-hearth steels were produced at proper speed—"hasting well by abiding wisely."

WRITTEN DISCUSSION

W. WEST:[4] Mr. Melmoth's paper revives once again the much-debated difference between two steels made by two different furnace operations. Usually it has been a comparison between tropenas steel and electric steel; in this case the open hearth substitutes for the pneumatic process.

That a difference exists in ordinary practice is incontrovertible, but the lack of consideration of two or three factors of vital importance causes the author's attempt to explain the difference to be totally inadequate.

First Factor.

Where two furnace operations are being considered, one of which provides for a much higher temperature being attained than the other, it is not unreasonable to suggest that to have obtained the temperature of the metal produced in each furnace would have given a sounder basis on which to build up any comparison.

This essential difference in operation between the two furnaces forwards the possibility of a greater superheat in the electric furnace, as mentioned in paragraph 28, where the author states that the effect could be found in samples cast near the end of the pour. It is quite possible, however, to raise the temperature of the steel in the furnace and produce an abnormal effect, such as the mass ferrite formation, so that no amount of heat treatment will eradicate the structure initially formed, and hence poor mechanical results are obtained.

In this paper we are asked to compare two series of results, without any confirmation that the temperature of production in either furnace was given any consideration whatever, a factor of such important magnitude that any conclusions based thereon might not only be of no service, but definitely misleading.

It might be further suggested that the greater tendency for these abnormalities to occur in electric steel coincides with the fact that the greater margin of heat available enables the manufacturer to produce a lighter and smaller type of steel casting, thus furnishing at least one answer to paragraph 2. Any superheating possible in one furnace, therefore, will carry with it a corresponding tendency for an increase in non-metallic inclusions, and also in a finer state of division of emulsification.

Second Factor.

The conclusions that the author has drawn from the second series of tests are not well founded. That a 0.27 per cent carbon open-hearth steel should be compared with 0.21 per cent carbon electric steel is totally inadmissible, and should have been rejected in the first place as a very indifferent source of comparison. To attempt to rectify the error by a recommended formula adds to the confusion of the issue.

In paragraph 19 the author reasons that a fall in elongation in the open-hearth specimen badly lowers the quality factor. Herein lies the inherent weakness of such a mathematical calculation in estimating such factors. It could not be expected that the two steels of the second series

[4] The Farington Steel Foundry of Leyland Motors, Ltd., Lancashire, England.

would give anything like the same percentages of elongation, yet such a fundamental factor is totally absorbed in the formula, and by some mystic process of mathematical conjuring a quality factor is involved.

Such quality factors are much too frail for any serious conclusions to be drawn therefrom.

Third Factor.

Experience has shown that in most cases electric steel requires a slightly higher annealing temperature than either open-hearth or tropenas steel, due no doubt to the ever-present possibility of a higher temperature having been reached in the melting furnace.

If this fact is admitted, then it might have been possible to have obtained better results from the electric steels in Series 1, by raising the first annealing temperature to 920 degs. Cent. This at least is what has been proved beyond question on this side, and of which the data of Table 6 give confirmation.

General Criticism and Suggestions.

More could have been stated in the paper to good effect relative to non-metallic inclusions, for the results of mechanical tests are greatly influenced by their character. Whatever ultra-microscopic inclusions might be present, it is a very difficult proposition to entirely eliminate or prevent

Table 6

TYPICAL RESULTS FROM BASIC-LINED ELECTRIC FURNACE STEEL

Chemical Analyses

Cast No.	C	Si	Mn	S	P
A707	0.19	0.34	0.68	0.014	0.020
A692	0.19	0.45	0.71	0.016	0.024
A697	0.20	0.38	0.59	0.014	0.022
A716	0.19	0.44	0.63	0.020	0.022
A711	0.20	0.40	0.65	0.016	0.020
A705	0.18	0.43	0.67	0.012	0.022

Mechanical Tests

	Original Dimensions			Maximum Stress			Bend Test	
Cast No.	Length in.	Diam. in.	Area sq. in.	Lbs. on Section	Lbs. per sq. in.	Elongation, %	Dimensions in.	Angle of bend degs.
A707	3	0.798	0.50	35,775	71,550	30	1 x ¾	120
A692	3	0.798	0.50	35,775	71,550	31	1 x ¾	120
A697	3	0.798	0.50	35,775	71,550	31	1 x ¾	120
A716	3	0.798	0.50	37,350	74,700	29	1 x ¾	120
A716	3	0.798	0.50	36,900	73,800	29	1 x ¾	120
A711*	2	0.564	0.25	18,225	72,900	29	1 x ¾	120
A705	3	0.750	0.44	32,175	73,105	28	1 x ¾	120

* Lbs. on section, 13,500; lbs. per sq. in., 5400.

NOTE: All samples annealed at 920 degs. Cent. for two hours, cooled in air from 600 degs. Cent.

their formation. We are not without hope, however, and this hope lies in effective heat treatment of the steel.

Briefly, the writer has found that where poor results with electric steels are due to these non-metallic particles, they occur more often than not in a streaky formation, which provides ideal lines of fracture through the ferrite areas, thereby giving decreased percentages of elongation.

It is possible, by increasing the temperature and time of annealing, to cause them to take the rounded or globular shape, when infinitely better results will be obtained.

With reference to the working conditions, the fact still remains open to be proved whether the production of a low-carbon steel melt before refining has any direct influence upon the properties of the finished steel. If it were altogether true, then it would be reasonable to expect infinitely poorer results from steel made in the basic electric steel furnace, as this is the fundamental feature of such a process.

The data in Table 6 give typical results obtained from a basic-lined electric furnace, which show no inferiority in quality to either acid electric or open-hearth furnace steel.

There are, in the writer's opinion, three defective practices in electric furnace steel making, which result in deficient quality. These practices are as follows:

1—Excessive superheating of the steel bath.

2—Accelerated and defective refining process.

3—Unsuitable heat treatment.

WRITTEN REPLY BY AUTHOR

F. A. MELMOTH: I thank Mr. West for his candid criticism, which, so long as it was accompanied by constructive ideas on the subject, was just what the author had hoped to call forth. Although the author's attempt unfortunately appeals to Mr. West as "totally inadequate," it probably has achieved its purpose in producing an accelerated application of thought to steel making problems directly affecting steel castings quality.

The possibility of temperature variation between the two processes at some period during the manufacture was dealt with at the presentation of the paper. It also is realized that the intense localized heating effect of the arcs may play a part difficult to assess correctly.

The obtaining of accurate temperatures of molten steel in differing conditions of production is not yet, in the author's opinion, a completely satisfactory operation, and the results are apt to be misleading. If, however, there have been developments in Europe which tend toward the

more reliable obtaining of such figures, the author would much appreciate a descriptive communication from Mr. West.

Our open-hearth steel is used for very many castings of thin section, and is necessarily cast hot for this type of material. For the comparisons which were made in the paper, it was therefore not necessary to make any remarkable effort to endeavor to bring temperature conditions as near into line as practical considerations demanded. The usual furnace tests were applied to insure not too wide a divergence.

It would add considerably to the value of Mr. West's comments if he would be prepared to state the evidence on which he bases his statement that "Any superheating possible in one furnace, therefore, will carry with it a corresponding tendency for an increase in non-metallic inclusions, and also in a finer state of division of emulsification."

I do not agree that, for the point in question, a variation of 0.06 per cent carbon content should cause the rejection of the conclusions drawn. While all formulas designed to give an overall idea of steel quality are distinctly open to criticism, a study of most of them will show that, within limits, a gain of strength, such as would be expected from an additional 0.06 per cent of carbon, tends to balance the depreciation of the final figure due to the normal elongation fall.

The author does not propose, however, to argue the question of merit formulas which, up to now and as stated above, are open to distinct criticism. Nevertheless, he does not agree that they can be described as "some mystic process of mathematical conjuring." The various men who have attempted their construction should at least be given credit for honesty of purpose.

In reply to the paragraph regarding the possible beneficial effects of higher annealing temperature, steel possessing this abnormal structure has been subjected to much more drastic treatment than that suggested, without noticeable benefit.

The test data enclosed by Mr. West are of interest, and they would have been more so if the yield point and reduction of area had been quoted. We are realizing that these two factors are of prime importance and that both are more extensively and quickly affected by certain influences than are the rest of the tensile test factors. The tests given by Mr. West are, of course, from basic electric material and are therefore not relevant to a discussion which is necessarily confined to acid material, which constitutes the vast majority of the production from electric furnaces in this country.

In general, Mr. West is in error if he interprets the paper as an attack upon electric steel. Far from being so, it is in the nature of an appeal for further study to insure the reputation of what can be an admirable material, but which possesses dangers in some hands owing to the very efficiency of the process from the point of view of speed.

Mr. West also confuses the issue by introducing the basic process. The writer has had sufficient experience with the basic process to realize the differences both in slag constitution and behavior. The paper is essentially in reference to acid practice, with which Mr. West had considerable experience some years ago. A reference to his experience at the time would have a more vital significance than an attempt to argue, along

basic lines, conclusions (or rather, suggestions) arising out of the comparison of purely acid materials.

Mr. Batty's remarks constitute a complete statement of the necessity for cleanliness and the proper apportionment of time during the manufacture of steel for use in castings. The object of my paper was to endeavor to add a little to the possibilities of improvement from the metallurgical standpoint.

I am convinced that the day is very far past when it was considered satisfactory to melt a certain amount of raw material, kill it off by more or less crude methods and cast it into molds, with the pious hope that the ultimate casting would possess desirable properties. I believe that we can do very little today of greater value than to give confirmation, as often as ever we can, of the beneficial results to be derived from greater care and greater cleanliness and control in steel-making operations for steel in steel foundry work.

We must remove entirely from the minds of the buying public any of the old impressions, many of them grossly incorrect, of the conditions of production and capabilities of performance of steel castings. We must press forward every possible application of technical control, always with the aim of producing steel castings which as a whole can manifest the physical characteristics of good, high-quality steel.

The object of such papers as the present one can only be achieved in the resulting discussion of the subject such as eventuated in the case of the present paper. Finally, I would like to express my appreciation both of the criticisms and the discussion, which in every case have contained something constructive.

Bronze Pressure Castings

By J. E. Crown,* Washington

Abstract

The manufacture of bronze castings for pressure service demands a high-grade product. Successful production of this class of work is possible only with a full appreciation of the various factors involved. The factors listed of most importance are: Selection of alloys, design of pattern, allowance for machine finish, method of molding, character of cores, and type of heads and gates. The principal alloy used at the Naval Gun Factory for nonferrous pressure castings is stated to be copper 87.25 per cent, tin 9 per cent, zinc 3 per cent and nickel 0.75 per cent. The average pouring temperature is about 1950 degs. Fahr., although this varies with the design. A hydraulic cylinder casting is used as a typical case to illustrate the production factors involved.

1. The manufacture of bronze castings for pressure service demands a higher grade of product than is required of castings where pressure testing is not a part of the specifications. A casting apparently solid, free from surface defects, true to dimensions and fully acceptable as an ordinary casting, may fail miserably when subjected to the required pressure test.

2. Successful production of this class of work is possible only with a full appreciation of the various factors involved. So often the question is seen in technical papers, "What alloy should be used for pressure castings?" apparently asked with the belief that selection of the alloy would solve the problem. However, selection of the alloy is only one factor; equally important factors are: Design of the casting, design of pattern, allowance for machine finish, method of molding, character of cores, type of heads and gates.

*Master Mechanic, Foundries, U. S. Naval Gun Factory.

Note: This paper was presented and discussed before one of the nonferrous sessions at the 1931 convention of the American Foundrymen's Association.

Alloys

3. The choice of numerous alloys may be made, final selection being determined usually by other desirable properties or as a result of a manufacturer's previous success with a given composition. Following are a few of the red-bronze alloys that have been successfully used for pressure work:

Cu	Sn	Zn	Ni	Pb
88	10	2		
88	8	4		
87	9	3	1	
85	5	5	0	5

4. Regardless of the alloy selection, it is essential that extreme care be exercised in melting to prevent overheating, oxidation or gas absorption in order to obtain consistent results, uniform quality and the maximum physical properties.

5. Various types of furnaces are used for melting, including the pit-type crucible furnace using oil, gas, coal or coke as fuel, the reverberatory furnace or electric arc and induction-type furnace, all of which have their peculiar advantages.

6. The principle alloy used at the U. S. Naval Gun Factory for nonferrous pressure castings consists of 87.25 per cent copper, 0.75 nickel, 9 tin and 3 zinc, made by the natural-draft pit-type crucible furnace using coal for fuel in the bed and coke for side walls. Fig. 1 shows a battery of this type of furnaces.

Method of Melting Described

7. Following is the process regularly used: The required amount of copper is melted down, protected from oxidation by placing crushed charcoal in the crucible to form a covering for the metal. If the copper, after being melted, shows any indication of wildness, a small quantity of carbon-free manganese is added (rarely exceeding 1 oz. per 100 lbs.), and to this bath is added the nickel, preferably in the form of copper-nickel hardener; then the tin is added and, finally, the zinc.

8. The entire charge is then permitted to remain in the furnace for sufficient time to permit complete solution of all ingredients. The metal is then pigged in iron molds, analyzed and later remelted for casting use, care being taken on remelting to prevent oxidation or overheating.

9. Proper pouring temperature is of vital importance and varies with the design of the casting. However, it may be generally stated that pouring temperature should be as low as is practical to obtain a well-run casting. The average pouring temperature at the Naval Gun Factory is 1950 degs. Fahr.

Design

10. Too frequently the influence of design on the problems encountered in the manufacture of pressure castings is not appre-

FIG. 1—BATTERY OF NATURAL-DRAFT PIT-TYPE CRUCIBLE FURNACES. COAL IS USED FOR THE BED AND COKE FOR SIDE WALLS.

ciated. Conditions exacting the use of all the resources of the foundryman often could be improved or eliminated by some slight change in design.

11. Wherever practical, design should permit uniform cross-section of metal, or the avoidance of sudden changes from one cross-section to another, keeping in mind that uniformity is desired at the time of pouring and that an allowance for machine finish may cause non-uniformity even though the finished product may be uniform.

12. The liberal use of fillets, avoidance of right-angle bends, maintaining of surface skin and the coring of heavy bosses are details of design which aid materially in the production of pressure castings. Fig. 2, *A* and *B*, show two methods of providing large boss on the side of a cylinder for attaching valve fitting. Fig. 2-*A*, showing a solid boss attached to a light wall, is poor design due to serious change in cross-section. Fig. 2-*B* shows the method of providing the same boss yet maintaining uniformity of cross-section.

13. A study of the foundry problems involved in the manufacture of pressure castings, especially those of intricate design, should begin on the drawing board.

Pattern Equipment

14. Accurate and well-designed pattern equipment is of major importance for this type of work to maintain the features studied in design, as incorrect shrinkage allowance, excessive machine finish or inaccurately fitting cores may defeat the very object sought in the original design.

FIG. 2—*A*, *A* SHOW POOR DESIGN OF BOSS DUE TO SERIOUS CHANGE IN CROSS-SECTION. *B*, *B* SHOW GOOD DESIGN OF SAME BOSS, GIVING UNIFORMITY IN CROSS-SECTION.

15. Too much stress cannot be placed upon the importance of proper machine finish allowance. As is well known, the grain size of bronze is in direct ratio to the rate of cooling—the more rapid the cooling, the closer the grain. Therefore, the metal that comes in direct contact with the mold being rapidly cooled has the best grain structure of the casting, and an excessive amount of machine finish, possibly allowed to take care of inaccurately molded castings, causes this close-grained metal to be removed by machining, thus exposing the more open-grained interior sections of the castings to withstand the required pressure.

16. Where practical, and whenever possible, match plates, set gates and similar devices should be used not only to reduce the cost of manufacture but to minimize the effects of the personal equation.

Molding

17. If the exercise of care, accuracy and intelligent planning is important in melting, designing and pattern construction, it is doubly so in molding to obtain success and counteract the normal variables found in foundry practice.

18. As design has attempted to maintain cast finish when possible, and as pattern construction has provided the minimum allowance for machine finish when machining is necessary, it is obvious that greater care must be exercised in the making of the mold and core to insure the final product being in accordance with desired dimensions.

19. Pressure castings may be cast readily in green sand except for the larger class of castings, when dry sand provides a greater factor of safety. Sand control insures more uniform results.

Type and Size of Gates Are Important

20. Selection of the type and size of gates should be given serious consideration in order to permit the entrance of metal to mold with the least amount of agitation and to distribute metal as far as possible to permit uniform rate of cooling in various sections. Chilling of heavy bosses may be necessary so as to aid in securing a uniform rate of cooling.

21. In some instances it is advisable to eliminate a shrink head which would normally be used on a non-pressure casting and to resort to chills. The shrink head not only keeps that section of

the casting liquid for a longer period, thus increasing its grain size, but its subsequent removal also destroys the skin effect.

Cores

22. The importance of the effect of the character of cores should not be overlooked, as they play an important part in the manufacture of pressure castings.

23. Cores should be made from sands having a high permeability. The binder material should be such as will give a strong body to the core yet having the feature of disintegrating at casting temperature, in order to permit complete collapse of the core and prevent any restriction to the normal contraction of the casting.

24. Cores must be well baked and thoroughly vented to permit rapid exodus of the gases, as the slight quivering of metal around the core, although it may not prove detrimental for certain castings, will prove fatal to pressure work.

Typical Hydraulic Cylinder Casting

25. Fig. 3 shows a casting of a hydraulic cylinder 21 inches in diameter, 10 feet long, an average wall thickness of 3/8 inch, weighing 2000 lbs. This was cast in dry sand of red bronze (87.25 copper, 9 tin, 3 zinc, 0.75 nickel composition), and tested to 300 lbs. per sq. in. pressure test after machining.

26. This casting was molded in a horizontal position with a split pattern, but was poured in a vertical position.

27. A 3-inch diameter down gate was provided for entrance of the metal, which connected with a circular runner around the core print to which were attached 24 down sprues having a total volume of one and one-half times the volume of the runner to prevent nozzle effect upon the metal. The entrance gate was extended 12 inches below the runner so as to break the fall of the metal and to permit easy flow of the stream to the casting.

28. A brick-lined reservoir of sufficient size to hold the full amount of metal was connected to the 3-inch sprue, the reservoir being equipped with a graphite stopper to permit holding of the metal until it was quiet and of the proper temperature for pouring. A shrink head was provided by extending the pattern 8 inches.

29. The design of the assembled unit, of which this casting

was to be a part, would not permit the use of a uniform section boss as shown in Fig. 2-*A*, but a compromise between the design of Fig. 2-*A* and Fig. 2-*B* was obtained for the rectangular pads, permitting the coring out of all excess metal and retaining only a sufficient surface as was required for attaching the valve. How-

FIG. 3.—CASTING OF 21-INCH DIAMETER HYDRAULIC CYLINDER 10 FEET LONG. GATING ARRANGEMENT SHOWS 3-INCH DIAMETER DOWN GATE CONNECTED TO CIRCULAR RUNNER AROUND CORE PRINT.

ever, even this difference in thickness was considered too great to permit proper cooling, and these pads were chilled.

30. Original design of this casting required machining of the entire interior, but a later design provided four narrow bearing strips running the entire length of the cylinder with cast finish between the strips, and danger of leakage was reduced.

31. A loam core was used for this casting so as to permit

maximum unrestricted contraction and to obtain more easily the desired accuracy of interior.

32. The general principles discussed in this paper have been applied in the manufacture of numerous pressure castings of intricate design at the U. S. Naval Gun Factory, resulting in lowering the percentage of rejections for castings required for pressure service.

DISCUSSION

N. K. B. PATCH:[1] I was very much interested in the type of gating described. As I understand it, it is what is called the shower gating principle.

There is a good deal of debate about whether one can get a pressure casting or not by this method, because of the effect of the cooling of the metal as it showers down through the mold. It would seem to me that the author has definitely indicated that it is possible to make castings which do not show the characteristics that we know of as resulting from the cooling of the metal in its fall.

MEMBER: What was the size of the small gate—the shower gate?

J. E. CROWN: In this particular casting, the small gate was approximately one inch wide and three-eighths inch thick.

MEMBER: Mr. Crown, how do you take care of the shrinkage of that casting? It would seem to me that the gates probably would freeze up.

J. E. CROWN: The casting itself is extended about eight inches higher than the casting proper, the upper eight inches being the shrink head.

Commenting on Mr. Patch's remarks about the value of drop pouring, in a casting of this type, where the wall is thin and the area is large, there is a choice between several undesirable conditions. We chose this method as being the least troublesome.

In bottom pouring we all know that there is a possibility of a folding in of the dirt and scurf that is rising to the top of the metal. Furthermore, one gets just the reverse of solidification conditions that are desirable; the first metal to enter is in the head.

With drop pouring, the metal coming down in the shower has a tendency to constantly break up the floating light dirt and scurf, keeping it in motion and afloat. Moreover, proper cooling conditions are present, in that the metal is the coolest at the bottom and the hottest at the top.

[1] Secretary, Lumen Bearing Co., Buffalo.

N. K. B. PATCH: How many different types of alloys are used? I wonder if this method has been applied to high-shrinkage alloys such as manganese bronze or aluminum bronze.

J. E. CROWN: Our experience has been confined almost entirely to tin bronzes, not the high-shrinkage metals.

T. H. ADDIE:[2] In regard to Mr. Crown's answer, the yellow metals, too, are certainly used for pressure castings. In one of our high-tensile bronze alloys we go as high as 20,000 lbs. per sq. in. test pressure. Those are large castings in dry sand, of course. The New York board of water supply is using manganese bronze under a test pressure of 200 to 500 or 600 lbs. per sq. in.

Mr. Crown's drop method is very interesting. We have tried it successfully, and the theory is a very good one.

When dealing with a very thin casting (I understand it runs as thin as five-eighths inch), one is bound to have channels up through the castings, should the metal be forced up from the bottom. If the casting is thick enough the metal will be forced up and rolled over as it comes up; but if the casting is thin and long, eventually a point will be reached where the metal comes up through the channels and makes layers over the top.

If a system can be evolved of dropping the metal from the bottom of a basin and filling the basin first, as Mr. Crown does, then the cleanest metal is coming from the bottom and the metal from the top is being fed in layers instead of being rolled over from a bottom pour. The oxide and dross, coming from the bottom, lay themselves on the outside when forced from the bottom, whereas, in dropping from a full basin, one gets the best metal all the time.

Mr. Crown spoke of the closest grained metal being on the outside skin, and the consequent need for cutting down the amount of machine work so as not to go below this dense structure. We get around this problem to some extent by chilling where we have to machine rather deeply with our large castings. The dense metal at the surface is augmented by the chilling action.

The chilling, of course, varies with the thickness of the chill. Very often, on irregular castings or sections that cannot be fed from a riser, where the thick section is too far from the riser, chilling will help. Chilling also is resorted to in order to obtain the dense structure desired in a pressure casting.

MEMBER: Mr. Crown, what is the metal temperature when you pour the casting you mention?

J. E. CROWN: The average temperature for this job is 1950 degs. Fahr. I suppose that in actual practice the first casting was poured at 2000 degs. Fahr., the next one at 1975 and the next one at 1950 degs. Fahr. At the latter point we felt that we had gone just about as far down as was safe.

I would like to mention here one thing about the gate and our ex-

[2] President, American Manganese Bronze Co., Philadelphia.

perience with it. Of course, the drop gate is common practice, but with the first one we made we used the regular method of allowing the gate to extend through the cope, and then prepared for pouring. The molder put the gates in position and rammed up his runner, but we did not get very good results on the product.

At first we thought our trouble lay possibly in the method of pouring. However, we discovered that the cause of our difficulty was just plain dirt, regardless of how much precaution we tried to take. The molder, in putting the gates back and ramming up his runner, got sand down into the mold, which caused trouble.

This experience resulted in our devising the gate that permitted it to be completely molded. Now it is only necessary to lift the gate and place it in position; no ramming is done after the mold is put together.

MEMBER: Has the author made any aluminum castings by the method he describes?

J. E. CROWN: We made aluminum castings and the somewhat notorious heat-treated aluminum castings. However, we have not drop poured these.

With the aluminum, we have attempted to put the gate at the lowest possible point, placing it so that the metal will get as great a run as possible without meeting obstruction, and we have tried to place the gate so that it will have some control over the rate of cooling of the casting. We have found, for instance, where a casting is light in some sections and has heavy bosses attached, that unless we so place the gate that the cooler metal will be sure to enter the heavy bosses, and even resort to chills, we get so much lower physical values at those points that it is objectionable. However, we never have drop poured aluminum.

ELMER RAE:[3] The drop pouring of aluminum surprised me greatly when I tried it out on some big crankcases, but I found that by changing the gate over to drop pouring, and practically making the gate all over the top of the casting very thin, that the castings have about five per cent leakage, against 90 per cent by pouring in at the sides or at the bottom. It certainly has improved our castings immensely by pouring at the top and cutting down on the risers, because the hot metal goes into the casting last at the top, where we want it hot.

[3] Foundry Superintendent, Wright Aeronautical Corp., Paterson, N. J.

A Grain Distribution Index for Sand Grading*

By Clarence E. Jackson,† Washington

Abstract

The present development of the American Foundrymen's Association grading classification is briefly discussed. The need for a grain distribution index is pointed out. Previous methods suggested for this determination are reviewed. A method is developed, based on statistical analysis, that yields a numerical value for a grain distribution index. Directions for the use of the method are given, and the method is used in application to actual sand samples.

1. The American Foundrymen's Association has recently adopted standard methods[1] for grading and classification of molding sands according to clay content, grain fineness and grain shape. The clay content of a molding sand, determined as the per cent by weight of the total sample which is clay substance, is designated by the letters A to J, each letter representing an arbitrary range or zone of per cent.

2. The grain fineness number, which is approximately the mesh of the sieve that would pass the sample if its grains were of uniform size, is calculated from a standard sieve analysis representing the per cent by weight of the different sized grains in the sample. In classifying molding sands, the fineness numbers are separated into ten arbitrary zones or ranges, each of which is indicated by a number.

* Publication approved by Director of the Bureau of Standards, U. S. Department of Commerce.

† Scientific Assistant, Bureau of Standards, U. S. Department of Commerce.

[1] *Testing and Grading Foundry Sands.* Standards and Tentative Standards, American Foundrymen's Association; new and revised edition, March, 1931.

Note: This paper was presented and discussed before one of the sand control sessions at the 1931 convention of the American Foundrymen's Association.

3. Grain shape is classified as angular, sub-angular, rounded or compound according to the shape of the individual grains.

4. The distribution of the sizes of the sand grains, or the grain distribution, is an important factor which is not considered in the above system of classification. A. A. Grubb[2] states: "Grain distribution is an important factor in determining certain molding properties, as is shown by the data of Table 2 on four sands of the same grain fineness but differing widely in grain distribution."

5. A copy of the table to which Grubb refers is shown herewith as Table 1.

6. It may be seen from a study of Grubb's table that, although sands may have the same grain fineness classification, certain of their physical properties such as permeability, density and bond strength will vary, to some extent, with changes in the grain distribution.

7. Several methods[3] have been suggested for the determination of a grain size distribution index. Of these, the Tyler and the Calculative methods have received the most attention.[4]

8. In the Tyler method the sieve analysis is plotted cumulatively. By graphical interpolation, it is possible to determine the two mesh openings which will, respectively, pass 60 and 10 per cent of the sample. The ratio of the first to the second of these mesh openings is taken as the distribution coefficient.

9. The Calculative method determines, approximately, the average size of the sand grains. The reciprocal of the number representing the average size of the sand grains is taken as the average mesh number or coarseness factor. The variation in the ratio of this average mesh number to the grain fineness number, as determined by the American Foundrymen's Association standard procedure, is taken as indicative of the grain distribution.

10. Both the Tyler and Calculative methods prove rather cumbersome to use.

11. The simple and direct method given below is based on

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[2] Grubb, A. A., *Some Recent Advances in the Field of Foundry Sand Control.* TRANSACTIONS AND BULLETIN, American Foundrymen's Association, vol. 1, no. 12, December, 1930, p. 41.

[3] *Report of Sub-Committee on Grading.* TRANSACTIONS, American Foundrymen's Association (1927), vol. 35, p. 189.

[4] *Report of Committee on Grading.* TRANSACTIONS AND BULLETIN, American Foundrymen's Association, vol. 1, no. 10, October, 1930, p. 511.

Table 1

IMPORTANCE OF GRAIN DISTRIBUTION IN MOLDING PROPERTIES—FOUR SANDS OF SAME GRAIN FINENESS BUT WIDELY DIFFERENT GRAIN DISTRIBUTION.

Fineness.	Sand No. 1.	Sand No. 2.	Sand No. 3.	Sand No. 4.
On 20	0	0	0	0
30	0	0	5	23
40	0	7	18	19
50	0	12	25	17
70	100	71	30	15
100	0	8	14	12
140	0	2	6	8
200	0	0	2	5
270	0	0	0	1
—270	0	0	0	0
Grain Fineness	50.0	50.0	50.0	50.0
Permeability:				
Dry	127	111	95	85
Tempered	210	187	160	125
Density (dry) grams per 100 cc.	166	171	177	184
Green bond (tensile), oz.	1.25	1.41	1.55	1.75

the grain fineness number and the fundamental data obtained from the sieve analysis. The resulting index is proportional to the grain distribution—that is, the wider the variation in the sizes of the sand grains, the larger the index becomes.

12. In Fig. 1 the results of the sieve analysis of the sands given in Grubb's table are plotted graphically with the ordinate y, representing the per cent of each grain size, and the abscissa x, representing the corresponding size mesh numbers. The rectangular areas in the graph represent quantitatively the amount of grain material remaining on each sieve. The distribution of

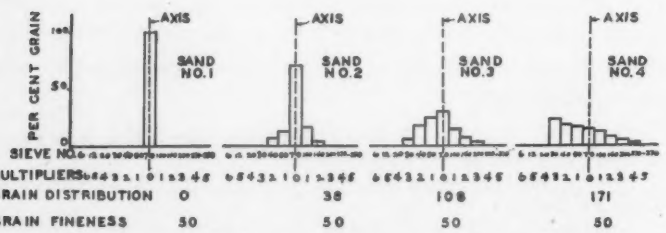

FIG. 1—DISTRIBUTION OF SAND GRAIN OF FOUR SANDS HAVING THE SAME GRAIN FINENESS.

these areas with respect to an axis determined by the grain fineness number will indicate the uniformity of grain size.

13. By statistical analysis of the data expressed graphically in Fig. 1, the uniformity and range of distribution or the scatter of the grain sizes may be determined as follows:

14. The second moment of each area concentrated at the mid-ordinate when the ordinates are equi-spaced about any axis is obtained by multiplying the ordinate y by the square of its distance x from the assumed axis. Dividing the sum of the second moments by the total frequency, which is represented by the total per cent of the molding sand which is grain material, will give the numerical value of the second moment about the assumed axis per unit frequency. Multiplying this number by 100 will give a result which may be taken as an index of the grain distribution on the basis of 100 per cent of the sand sample.

15. In order to reduce the amount of calculation and facilitate the determination of the grain distribution index, the distances x, which designate the position of the various mid-ordinates about an arbitrary axis (zero axis), may be taken as $-\sqrt{3}$, $-\sqrt{2}$, $-\sqrt{1}$, 0, $\sqrt{1}$, $\sqrt{2}$, $\sqrt{3}$, and so on along the x-axis. The first mid-ordinate to the right of that corresponding to the abscissa which is numerically nearest equal to the grain fineness number, is taken as the zero axis. The square of the distance of any ordinate from the zero axis will be 1, 2, 3, and so on, counting in order both to right and left of arbitrary axis.

16. The sands in Grubb's table have a fineness number of 50. It is to be noted that grains on a certain sieve must be too coarse to pass this sieve and fine enough to pass the previous sieve.

17. For example, in the case of sand No. 3, although the maximum ordinate is labeled 70 it indicates the per cent of sand grain that passed the number 50 sieve but remained on the 70 sieve. In this sand, sieve number 50 will be nearest equal, numerically, to this grain fineness number, and the first ordinate to the right of this, or that of sieve No. 70, will be the axis about which the second moment per unit frequency is to be determined. The calculation involved in determining the grain distribution index of sand No. 3 shown in Fig. 1 is given in Table 2.

18. In a similar manner, the grain distribution index for sands Nos. 1, 2 and 4 is found to be 0, 38 and 171, respectively.

19. No attempt has been made to classify the distribution index into zones such as are used in the present American Foundrymen's Association grading classification. The use of a grain distribution index as described in this paper, together with the present standard classification, will make possible a more exact description of any sand.

20. The procedure may be restated in a more usable and concise form as follows: From the sieve analysis of the grain material, determine the grain fineness number. Determine the sieve number which is closest to the grain fineness number. In case a grain fineness number is found equidistant from two sieve numbers, it is considered to be closest to the lower sieve number. Assign the number 0 to the sieve number next higher than the sieve number just determined. In some sands of wide distribution in grain size the assignment of the number 0 to the sieve number to which the grain fineness number is closest, will give a lower distribution index for the sand. The lower value is always to be taken as the distribution index. Assign numbers 1, 2, 3 and so on, to the standard sieve numbers, counting in order away from the number 0. Multiply the per cent of each grain size by these numbers, add the products obtained and divide this sum by the

Table 2

CALCULATIONS FOR DETERMINING GRAIN DISTRIBUTION INDEX OF SAND NO. 3 OF TABLE 1

Sieve No.	y	x^2	yx^2
20	0	4	0
30	5	3	15
40	18	2	36
50	25	1	25
70	30	0	0
100	14	1	14
140	6	2	12
200	2	3	6
270	0	4	0
—270	0	5	0
Total	100		108

Grain distribution $= \frac{108}{100} \times 100$ or 108.

Grain fineness $= 50$

Table 3

SAMPLE OF ALBANY MOLDING SAND

On sieve	Per cent		Fineness: Multiplier	Fineness: Product	Distribution: Assigned No.	Distribution: Product
6	0.0	×	3	0.0	10	0.0
12	0.1	×	6	0.6	9	0.9
20	0.2	×	10	2.0	8	1.6
30	0.3	×	20	6.0	7	2.1
40	0.4	×	30	12.0	6	2.4
50	0.8	×	40	32.0	5	4.0
70	1.6	×	50	80.0	4	6.4
100	7.0	×	70	490.0	3	21.0
140	16.2	×	100	1,620.0	2	32.4
200	17.3	×	140	2,422.0	1	17.3
270	12.8	×	200	2,560.0	0	0.0
—270	30.8	×	300	9,240.0	1	30.8
Total	87.5			16,465.6		118.9

Clay substance 12.5 per cent.

Grain fineness $= \frac{16{,}465.6}{87.5}$ or 188.

Grain distribution $= \frac{118.9}{87.5} \times 100$, or 135.

Classification: 2-E, 135, sub-angular.

Table 4

SAMPLE DOWNER STEEL SAND

On sieve	Per cent		Fineness: Multiplier	Fineness: Product	Distribution: Assigned No.	Distribution: Product
6	0.0	×	3	0.0	7	0.0
12	0.0	×	6	0.0	6	0.0
20	0.8	×	10	8.0	5	4.0
30	1.2	×	20	24.0	4	4.8
40	3.4	×	30	102.0	3	10.2
50	4.4	×	40	176.0	2	8.8
70	29.6	×	50	1,480.0	1	29.6
100	32.2	×	70	2,254.0	0	0.0
140	12.2	×	100	1,220.0	1	12.2
200	1.5	×	140	210.0	2	3.0
270	0.4	×	200	80.0	3	1.2
—270	1.3	×	300	390.0	4	5.2
Total	87.0			5,914.0		79.0

Clay substance 13.0 per cent.

Grain fineness $= \frac{5{,}914.0}{87.0}$ or 67.

Grain distribution $= \frac{79}{87} \times 100$, or 90.

Classification: 5-E, 90, sub-angular.

total per cent which is sand grain. This result, multiplied by 100, gives the grain distribution index of the sand sample.

21. For example, in a typical Albany molding sand the grain fineness number was found to be 188 (see Table 3). The sieve number which is closest the grain fineness number will be 200. To the sieve number which is next higher than this number, or number 270, is assigned 0. The numbers 1, 2, 3, and so on, are assigned to the sieve numbers 200, 140, 100, and so on, counting in order from sieve number 270 toward the coarsest sieve. Counting in order from the sieve number 270 toward the finest sieve, No. 1 is then assigned to the —270 material. The per cent of each grain size is multiplied by these assigned numbers. The sums of the products—which in this case is 118.9—is divided by the total per cent of sand grain, or 87.5. This result, multiplied by 100, gives the grain distribution index of 135 for this sand (see Table 3).

22. In Table 4 is shown a similar application of the use of the grain distribution index determination to the classification of a typical steel molding sand. The change in the position of the zero axis is to be noted.

DISCUSSION

C. E. JACKSON: The permeability of a sand may be controlled to a certain extent by varying either the average grain size or the distribution of grain sizes. Theoretically, a sand with uniform grain size will have a maximum permeability. A lack of uniformity in the sand grain sizes will lower the permeability.

A standard method now is used for determining the average grain size. An attempt is made in the paper as presented to give a method for measuring the distribution of grain sizes in a sand.

MEMBER: Is there any relation between permeability and this grain distribution?

C. E. JACKSON: As yet no laboratory study has been made, although the permeability should decrease with an increase in the distribution factor. That is, the higher the distribution factor (the wider the distribution of sizes), the more compact the grains will be.

A Practical Method for Studying the Running Quality of a Metal Cast in Foundry Molds*

By C. M. Saeger, Jr.,† and A. I. Krynitsky,** Washington

The ability of molten metals to fill foundry sand molds is related to the fluidity of the molten metal and also to the "running qualities" as affected by the sand mold prepared under various conditions. A test method for determining the "running qualities" of metals has been developed. Such tests were conducted for aluminum, brass and cast iron in both dry and green-sand molds. The results indicated that the metals cast in dry-sand molds ran further than the same metals cast in green-sand molds; that with an increase in pouring temperature, the length of test specimens increased in direct proportion to the pouring temperature; that the maximum heating temperature before pouring had an effect on the results of aluminum.

Introduction

1. One of the important problems regularly encountered in foundry practice is the determination of the "ability" of a molten metal in a given condition to fill a mold prepared under determined conditions. This quality of a molten metal to fill a sand mold has often been considered as being equivalent to the fluidity of the molten metal. Fluidity, which may be defined as that property of the molten metal which is the converse of viscosity, is a fundamental property of the liquid.

2. Foundrymen, however, are not particularly interested in the fluidity of the metal itself, but in the ability of the metal to fill, completely, molds which may have been prepared under various conditions. The ability of a molten metal to fill a mold cavity rapidly and completely depends upon a number of factors, of which the fluidity of the metal is only one.

* Publication approved by Director of the Bureau of Standards, U. S. Department of Commerce.

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Note: This paper was presented and discussed before two sessions at the 1931 convention of the American Foundrymen's Association.

3. When liquid metal is poured into a mold, it flows through the more or less intricate design of the mold cavity as a result of the hydrostatic head pressure of the liquid metal. A number of factors, combined, oppose this flow.

4. One factor is the internal friction or viscosity of the liquid metal itself; the work which must be done when liquid particles are pushed past each other. Flow of metal through the mold also is retarded by the friction between the liquid and the surfaces of the mold cavity, this effect being greatly influenced by the nature of the grain of the sand, the nature of the mold facing materials used, and by the degree of packing of the sand.

5. Surface tension of the liquid metal against the sand surface also plays a part in opposing flow of the liquid metal, as also do oxide or other films formed on the surface of the liquid metal.

6. Retardation of flow may result from gas pressure developed in that part of the mold cavity not yet occupied by the metal, this pressure being due to gases from the mold and, possibly, to some extent from the cooling metal. The degree to which this pressure retards further flow of metal is determined upon the mold design, the moisture content of the mold material and the permeability of the sand as rammed in the mold.

7. As long as the metal possesses sufficient heat to keep its temperature above its freezing point, and as long as the head pressure of metal is maintained in excess of the summation of all the factors opposing the flow of metal, the mold continues to fill.

8. Obviously, the heat content of the liquid metal entering the mold is balanced against the rate of transfer of heat from the metal to the mold and the heat capacity of the mold. Viscosity of the metal, turbulence during pouring, reaction of the liquid metal, sand-metal interface, and the moisture content of the sand, all naturally play major parts in determining the rate at which heat is conducted from the liquid metal.

9. All of these factors must be considered in attempting to define and study that property of a liquid metal which the foundryman has been inclined to designate simply as fluidity. This term clearly is not correct.

10. The choice of a simple, short term to designate this property of molten metals is difficult. There is no single English word which expresses the idea involved.

11. The term "coulabilité," originated by Portevin, has been adopted generally by French writers*[6] on the subject, and some attempt has been made to introduce this into American foundry practice.[3] Likewise, the term "runability" has been proposed as being expressive of the property and is used to a limited extent in shop parlance. The term "running qualities" is perhaps as expressive and satisfactory as any, and, as such, is used throughout this paper.

PREVIOUS WORK

12. T. D. West,[1] in 1898, probably was the earliest investigator to study the properties of molten metals as cast into sand molds. An elongated wedge-shaped casting poured horizontally was used.[3] The distance in inches that the molten metal flowed into the wedge was used as an indication of the fluidity of the metal.

13. Ledebur[4] in 1904, Sexton and Primrose[4] in 1911, and Moldenke[3] in 1917, modified the wedge casting somewhat. However, the distance that the molten metal flowed, in inches, into the wedge type of casting was used as an indication of the fluidity of the molten metal.

14. Saito and Hayashi,[2] in 1919, devised a spiral casting method for determining the casting or running qualities of molten metal cast in dry-sand molds. A relatively long casting of small cross-section was obtained in the form of a flat spiral.

15. This method made use of a receiving crucible equipped with a stopper which, when removed, permitted the molten metal to flow through a gate into the outer end of a spiral. The inner end of the spiral was provided with a riser to allow the escape of mold gases. The length of the spiral casting—that is, the distance which the metal flowed when poured—was taken as an indication of the casting quality of the metal for the particular pouring temperature used. A number of metals and alloys were investigated.

16. According to Curry,[4] Remy (in 1922) modified this method by eliminating the stopper in the receiving crucible and by pouring the metal directly through a small gate leading into a blind reservoir of such dimensions as to permit the metal to

* Reference numbers as shown in this paper correspond with similar numbers given in the Bibliography at the end of the paper.

penetrate into the spiral only after the receiving crucible had been filled. The blind reservoir consequently regulated the speed of the molten metal flowing through the spiral.

17. Curry,[4] in 1924, continued the investigation of the method and made several modifications, the principal one involving a change in the cross-section of the spiral from a circular to an inverted triangular form. He also provided a pouring basin containing a three-hole filter core through which the metal flowed down into a blind reservoir and then into the inner end of the spiral casting.

18. After the completion of the Bureau's experimental work, an article by Courty[6] appeared in which the method of spiral casting was still further modified, the principal change consisting of the use of a chill or metal mold. The method of feeding the metal into the mold so as to maintain a constant head also was modified.

PRELIMINARY INVESTIGATION OF THE METHOD OF SPIRAL CASTING

19. In the present study of the running qualities of metals, the method described by Curry[4] was first employed. A wooden

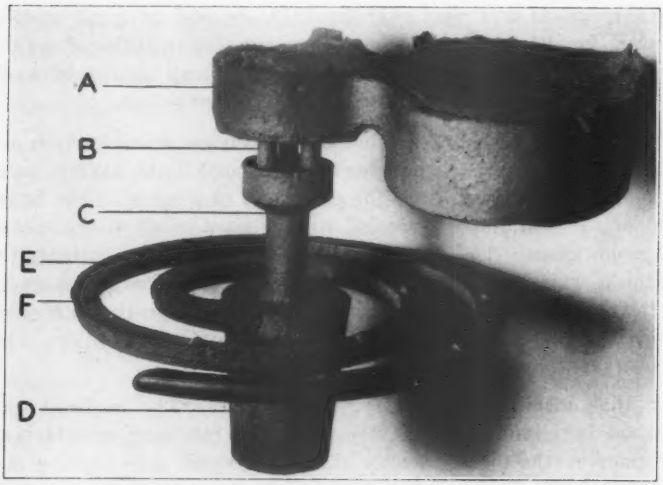

FIG. 1—CAST-IRON SPIRAL MADE ACCORDING TO CURRY'S DESIGN. A: POURING BASIN. B: THREE FILTER GATES. C: DOWN GATE. D: BLIND RESERVOIR. E: SPIRAL CASTING. F: RAISED LENGTH REFERENCE MARKS.

pattern was prepared, of dimensions such as are shown in his paper. Fig. 1 shows a typical casting made after this pattern.

20. Curry concluded from his investigation of the fluidity of molten metals, that

(a) any obstruction, or irregular shape, or any loose sand washed away from the filter cores, influences the results considerably;

(b) it is important that the molds be level in order to obtain consistent results;

(c) variable amounts of moisture in molding sands do not markedly affect the fluidity of the molten metals;

(d) venting of the end of the spiral has no influence on the resulting length of the spiral castings.

Table 1

Effect of Venting on the Running Properties of Cast Iron as Measured by the Length of Spiral Castings Made According to Curry's Method

Molds.	Pouring Temperature. Degs. Cent.	Degs. Fahr.*	Length. Inches.	Mm.
Riser	1525	2775	44.7	1135†
No riser	1525	2775	44.7	1135†
Riser	1360	2480	35.5	903
No riser	1360	2480	31.7	805
Riser	1310	2390	23.8	605
No riser	1310	2390	23.2	590

* "Rounded off."
† Ran full length of spiral.

Venting.

21. In the first phase of the investigation, castings were made with and without a riser located at the outer end of the spiral. To accomplish this, three molds having ¼-inch risers, and three molds without risers, were prepared in dry Lumberton sand. Castings were made in these molds in pairs, by means of a runner box. Each pair of molds consisted of one with a riser and one without a riser.

22. Table 1 shows the lengths of spiral castings obtained with

cast iron of commercial stove-plate grade. The pouring temperatures were measured with a platinum-to-platinum-rhodium thermocouple.

23. It may be noted from Table 1 that the molten metal ran somewhat farther in the spiral when risers were used, than when no venting was used. This evidently was due to the fact that any gases or steam formed in the mold could easily escape in the first case, whereas, when no risers were used, the gases ahead of the incoming metal had to be forced through the sand mold material under pressure and, therefore, retarded the metal flow. The degree of permeability of the molding sand as affected by the moisture present also would affect the fluidity results in a similar manner when no risers are used.

Filter Core.

24. As shown in Table 1, fluidity strips poured at 1525 degs. Cent. (2775 degs. Fahr.) ran the full length of the spiral in the mold used. This was believed to be due to the high rate of feeding of the metal through the three-hole filter core and also to the higher fluidity of the metal itself at this particular pouring temperature.

25. In order to obtain supporting evidence, tests were conducted in which the number of holes in the filter core was varied in order to vary the feeding rate. An overflow runner was attached to the pouring basin to maintain a constant pressure head of molten metal while the test was being carried out. To eliminate variables that might result from variations in the molding sand, a special mold-facing mixture was employed which consisted of the following materials:

	Per cent by weight
Sharp silica sand	80
Silica flour	8
Linseed oil	1
Water	11

26. Molds of Lumberton sand faced with the above mixture were placed in a core oven, dried, and cooled to room temperature before being used. The molds were assembled, before drying, in order to eliminate any parting between the cope and drag sides of the mold, which, in turn, would produce fins along the spiral

casting, thereby affecting the rate of flow of metal within the spiral cavity.

27. Table 2 shows the lengths of spirals of cast iron of stove-plate grade, cast with filter cores having one, two and three holes. The molds were cast individually at a pouring temperature of 1400 degs. Cent. (2550 degs. Fahr.).

28. Table 2 is representative of a large number of tests and shows clearly that the most consistent results were obtained by the use of two-hole filter cores. Further tests, using the two-hole filter cores, were made with cast iron containing nickel and nickel-chromium additions.

29. Heat "A", Table 3, contained 0.5 per cent nickel, and Heat "B" contained 1.3 per cent nickel and 0.5 per cent chromium added to stove-plate iron. The molds were prepared with the sand facing mixture and then dried as previously described. The re-

Table 2

Effect of Rate of Feeding on Running Properties of Cast Iron as Measured by the Length of Spiral Castings Made According to Curry's Method

No. of Holes in Filter Core.	Pouring Temperature.		Length of Spiral.	
	Degs. Cent.	Degs. Fahr.	Inches.	Mm.
1	1400	2550	19.1	486
1	1400	2550	14.7	374
2	1400	2550	26.4	672
2	1400	2550	24.7	628
3	1400	2550	32.3	822
3	1400	2550	23.9	607

Table 3

"Running Qualities" of Two Grades of Alloy Cast Iron as Determined by Curry's Method, the Rate of Feeding Being Determined by a 2-hole Filter Core

Heat No.	Pouring Temperature.		Length of Spiral Casting.	
	Degs. Cent.	Degs. Fahr.	Inches.	Mm.
A	1400	2550	33.7	855
A	1400	2550	32.2	818
A	1400	2550	26.8	682
B	1400	2550	25.5	647
B	1400	2550	22.9	582
B	1400	2550	19.6	497

sults of these tests, shown in Table 3, were inconsistent, and it was impossible to state definitely any reason for the order of the results obtained.

Modification of Method.

30. In view of the erratic results obtained when using cast iron for determining whether the method was satisfactory, it was decided to conduct further tests by modified methods and to use aluminum in the study of the various modifications in order to develop a sensitive and reliable method.

31. The first change in the method consisted in the elimination of the filter cores and down gates, and the replacement of them by a horn gate by which the metal was fed into a blind reservoir and then into the spiral casting (Fig. 2). These changes did not give any better results. Further modifications were made

FIG. 2—SPIRAL CASTINGS MADE WITH A HORN GATE.

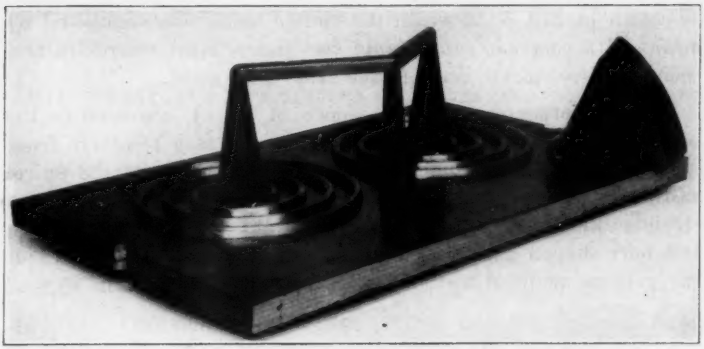

Fig. 3—Double Spiral Pattern Board.

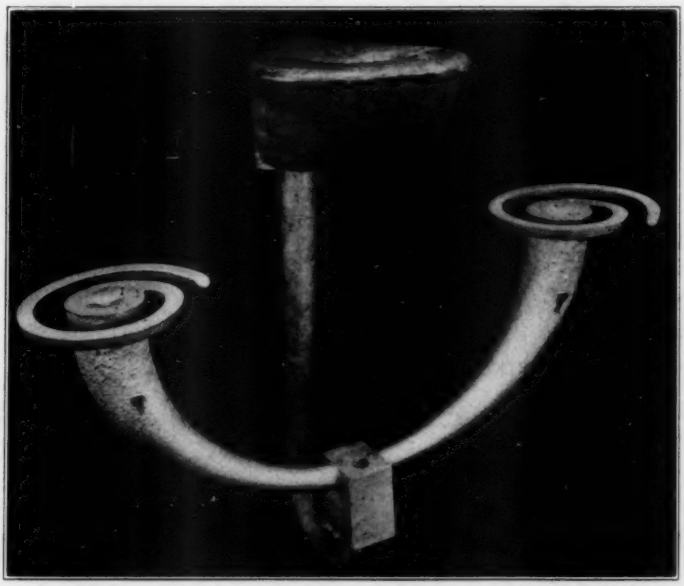

Fig. 4—Modification of the Double Spiral Casting with a Horn Gate.

as shown in Fig. 3, in which the molten metal was conducted by means of a common runner into two cone-shaped reservoirs and then into two spirals made in the same sand mold.

32. Another modification, shown in Fig. 4, consisted in the use of a horn gate to feed the molten metal to a reservoir from which it was fed through two horn-shaped gates to the spiral castings. This pattern was modified further by substituting a straight tapered gate to feed into the blind reservoir, from which two horn-shaped gates led to the spiral castings. The details of the various modified methods of casting are best seen in Figs. 2 to 4, inclusive.

33. None of the various modifications were satisfactory, as it was found impossible to duplicate the lengths of the spiral

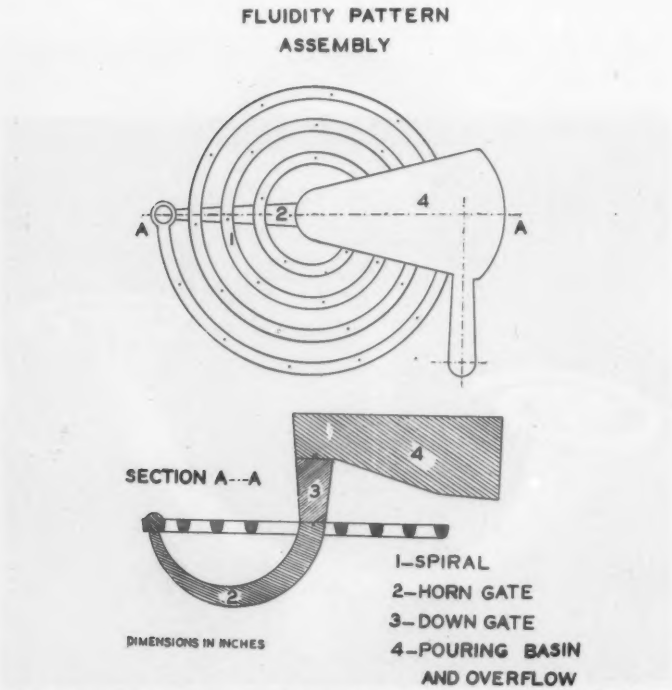

FIG. 5—ASSEMBLY OF FINISHED PATTERN USED FOR DETERMINING THE RUNNING PROPERTIES OF METAL.

castings when a series of castings was made at the same pouring temperatures.

Development of a New Method for Determining the Running Properties of Molten Metals

34. Because of the unsatisfactory results obtained by the various modified methods described, it was decided to change the design to an entirely new form of pattern, details of which are given in Figs. 5 to 9, inclusive.

35. The casting method employed is summarized briefly as follows: The molten metal was poured into the pouring basin, (4 in Fig. 5), which in turn fed the metal through the down gate (3) and through the horn gate (2) into the outer end of the spiral (1). By means of the overflow attached to the pouring basin (4) a constant pressure head of molten metal thus could be maintained.

36. The inner end of the spiral was vented with a down vent. Reference marks were placed at 2-inch intervals along the

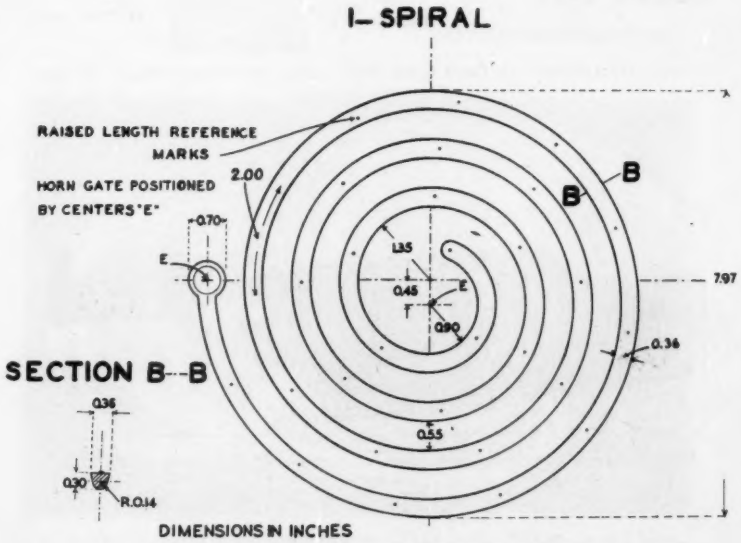

Fig. 6—Dimensions of Spiral in Finished Pattern.

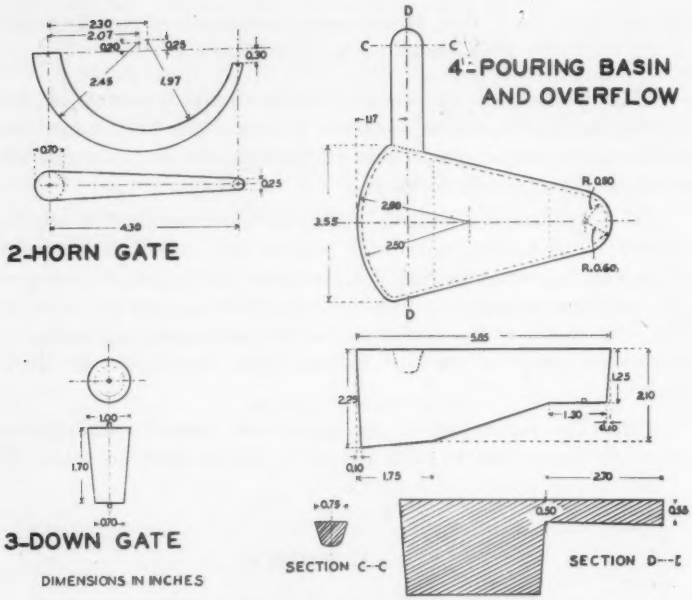

FIG. 7—DIMENSIONS OF HORN GATE, DOWN GATE AND POURING BASIN IN THE FINISHED PATTERN.

FIG. 8—BRASS PATTERN BOARD MADE ACCORDING TO THE DESIGN IN FIGS. 5, 6 AND 7.

spiral to aid in determining its length quickly. The total length of the spiral was 60 inches.

Metals Investigated by New Method

Aluminum

37. Table 4 shows the results obtained in a series of preliminary tests with commercial aluminum cast in Grade No. 00

Table 4

The "Running Qualities" of Commercial Aluminum as Measured by the Length of Spiral Castings Made by the Method Developed at the Bureau.

Pouring Temperature.			Length of Spiral.
Degs. Cent.	Degs. Fahr.		Inches.
800	1472		23.2
800	1472		23.3
800	1472		23.5
800	1472		23.1
		Average	23.3
750	1382		15.5
750	1382		16.4
750	1382		15.4
750	1382		15.3
		Average	15.7

Fig. 9—Spiral Casting of Aluminum in Green Sand, Poured at 775 Degs. Cent.

Albany sand tempered with 6.5 per cent of water. Good agreement was obtained between castings poured at the same temperature—a number of the castings were poured on different days. The sensitivity of the method may be judged from the fact that an average difference in length of spiral of 7.6 inches was obtained for a difference of only 50 degs. Cent. (90 degs. Fahr.) in pouring temperature.

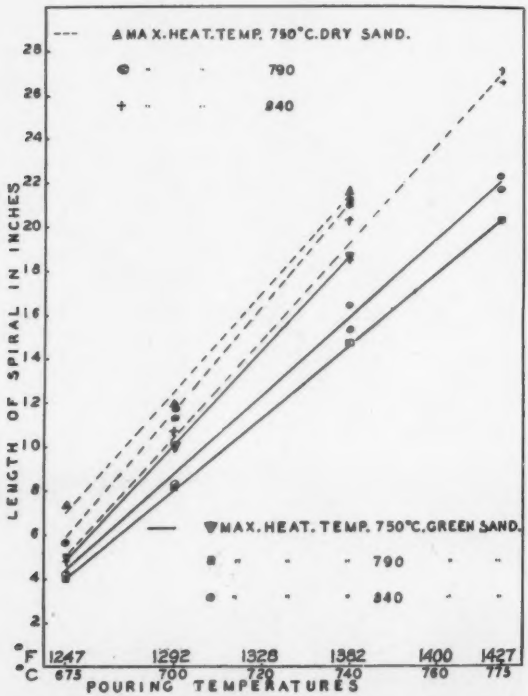

FIG. 10—RESULTS OBTAINED WITH COMMERCIAL ALUMINUM.

38. Further tests were conducted to study the "running qualities" of commercially pure aluminum as affected by the use of green- and dry-sand molds, the maximum heating temperature and the pouring temperature.

39. Both green- and dry-sand molds were made from No. 00

Albany sand. The green-sand molds were tempered with about 6.5 per cent of water. In making the dry-sand molds, the sand was first tempered with 6.5 per cent of water and the molds were then heated in a large gas-fired oven for three hours at 300 degs. Cent. (572 degs. Fahr.) They were then allowed to cool with the oven overnight, after which they were removed and cooled to room temperature.

40. All molds were carefully leveled before the metal was poured. Before the test mold was poured, some of the metal was poured out over the lip of the crucible to minimize the chilling effect of the cold lip.

41. Temperature measurements were made by means of a chromel-alumel thermocouple, which was also used in the experiments with red brass as reported hereafter. A platinum-to-platinum-rhodium couple was used for the experiments with cast iron.

42. The curves shown in Fig. 10 represent the results obtained on commercially pure aluminum melted in a gas furnace. Three maximum heating temperatures were used: 750 degs. Cent. (1382 degs. Fahr.), 790 degs. Cent. (1454 degs. Fahr.), and 840 degs. Cent. (1544 degs. Fahr.). The same pouring temperatures were used for both the dry- and green-sand molds, namely, 675, 700, 740, and 775 degs. Cent. (1247, 1292, 1364, and 1427 degs. Fahr., respectively).

43. The spirals cast in dry sand were consistently longer than those cast in green sand. The metal heated to a maximum temperature of 750 degs. Cent. (1382 degs. Fahr.) before pouring was found to have superior running properties, in both green- and dry-sand molds, to the metal heated to a maximum temperature of 790 or 840 degs. Cent. (1454 or 1544 degs. Fahr., respectively) before casting.

44. A possible explanation of this difference in behavior is that the molten aluminum at the heating temperatures of 790 degs. Cent. (1454 degs. Fahr.) and 840 degs. Cent. (1544 degs. Fahr.) absorbed "gas" in the furnace before casting.

Brass

45. Tests were conducted on red brass of the nominal composition 85 per cent copper, 5 per cent zinc, 5 per cent tin, 5 per

cent lead. Both virgin and remelted metal were used. A high-frequency induction furnace was used to melt the metal.

46. The same molding procedure as used with aluminum was used for the brass. The pouring temperatures used for the various heats of virgin metal were 1040, 1095, 1150, 1205 and 1260 degs. Cent. (1904, 2003, 2102, 2200 and 2300 degs. Fahr., respectively), and for the remelted metal they were 1095, 1150, 1205 and 1260 degs. Cent.

47. The results of these tests are plotted in Fig. 11. It may be noted that the virgin metal ran farther in dry sand than the virgin and the remelted metal ran in green sand, and also that the remelted metal ran farther than the virgin metal in the green-sand molds.

Cast Iron

48. By the same procedure as was used for aluminum and brass, the running qualities of a cast iron of the following composition were determined:

	Per Cent.
Combined Carbon	0.42
Graphitic Carbon	3.02
Total Carbon	3.44
Silicon	2.38
Manganese	0.74
Sulphur	0.04
Phosphorus	0.47

49. The metal was melted in a high-frequency induction furnace and heated to a maximum temperature of 1500 degs. Cent. (2732 degs. Fahr.). Pouring temperatures of 1275, 1325, 1355 and 1385 degs. Cent. (2327, 2418, 2471 and 2525 degs. Fahr., respectively) were used for the dry-sand molds and temperatures of 1285, 1330, 1362 and 1400 degs. Cent. (2345, 2426, 2484 and 2552 degs. Fahr., respectively) for the green-sand molds. The results obtained are summarized in Fig. 12.

DISCUSSION AND SUMMARY

50. Throughout the preceding discussion, the fact has been repeatedly emphasized that "fluidity" is a misnomer in referring to the foundryman's interest in the problem of the casting qualities of metals. The results obtained with aluminum, brass and cast iron serve to emphasize the fact that the "running qualities"

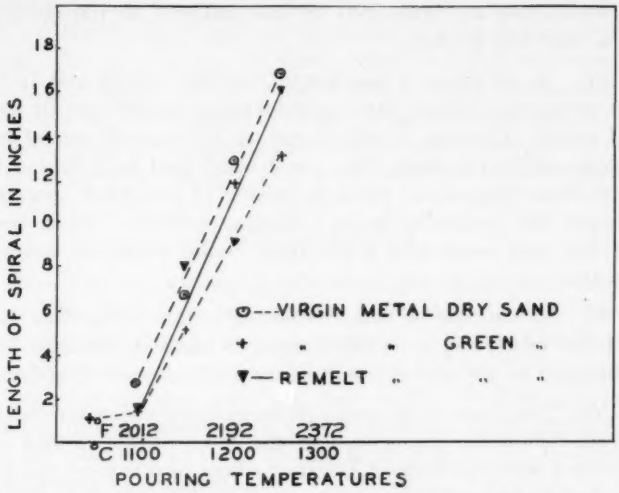

Fig. 11—Results Obtained with Virgin and Remelted Metal. Nominal composition: 85 Per Cent Copper, 5 Per Cent Zinc, 5 Per Cent Tin, and 5 Per Cent Lead.

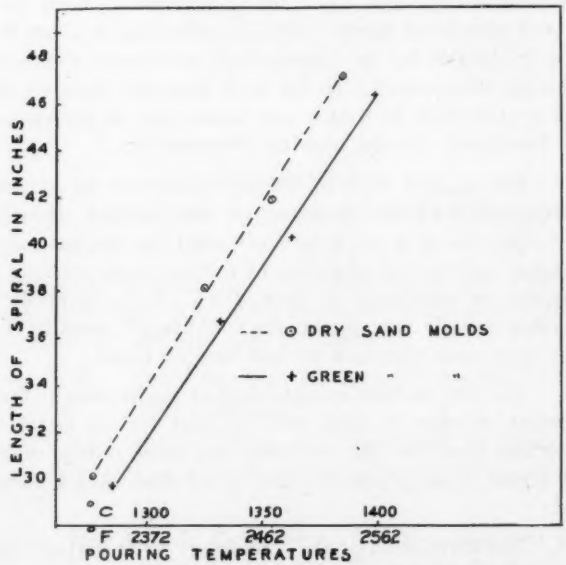

Fig. 12—Results Obtained with Cast Iron.

of these metals are influenced by the character of the mold into which they are poured.

51. In all cases, it was found that the spirals cast in dry-sand molds were longer than corresponding spirals cast in green-sand molds. Likewise, it was found, in the case of several heats of commercial aluminum, that metal which had been heated to a rather high temperature prior to casting at somewhat lower temperature, had noticeably lower "running qualities" when cast in both dry- and green-sand molds than similar metal not heated so strongly.

52. In the case of brass, remelting of the metal was found not to be deleterious in its effect upon the running qualities. This is contrary to popular opinion on the part of some foundrymen.

53. The linear relationship between the pouring temperature and the "running properties" of the three metals studied is in agreement with the work of Courty,[6] whose results were not available for study until the experimental work in this investigation had been completed.

54. According to Courty, it was necessary to raise the pouring temperature 3.9 degs. Cent. for an increase of 1 cm. in length of the cast aluminum spiral. This is equivalent to about 0.1 inch increase in length for an increase of one degree Centigrade in the pouring temperature. In the work described here, an increase of 0.13 to 0.26 inch in length was found for an increase of one degree Centigrade in the pouring temperature.

55. The method used by Courty represents an extension of and apparently an improvement on the method described by Curry.[4] The use of a metal or chill mold for the casting of the spiral limits the method to metals of relatively low melting points, such as zinc or aluminum or their alloys. It is extremely doubtful whether equally valuable results could be obtained in the same manner with such materials as cast iron or brass.

56. The test method as developed at the Bureau is free from this limitation, since a sand mold is used for all metals. It is believed also that the test conditions are more nearly representative of actual foundry practice than is the case when a metal mold is used.

57. The correlation of the "running" or "casting" qualities of a metal as determined by the test described here, or by any

other similar test with actual experience or practice, is very necessary, of course, in evaluating the merits and usefulness of such a test. An opportunity for such correlation has not been possible in the course of this work, which has been necessarily restricted to the development of a test method giving accurate and reproducible results. Such an attempt to determine the usefulness of the test practically should be made under commercial foundry conditions.

Acknowledgments

58. The cooperation of the Committee on Gray Iron Castings of the American Foundrymen's Association, since this investigation was first actively undertaken by the Bureau in 1929, has been greatly appreciated. Much credit is due L. D. Jones of the Foundry Section, who has done highly creditable work in assisting in the modification of the methods investigated. The valuable assistance of C. B. Riecks, E. J. Ash and H. B. Gardner also has been appreciated.

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DISCUSSION

ORAL DISCUSSION

L. A. WARD:[1] The first question I wish to ask is, how close can Mr. Saeger check his results, using this fluidity pattern?

The second question is, if the results are different in green sand than in dry sand, how much variation is due to a variation in the percentage of moisture in the green sand?

The third question is, is there any difference in results with different degrees or types of ramming the mold?

Lastly, has the author done any work using a permanent mold instead of a sand mold?

C. M. SAEGER, JR.: In answer to Mr. Ward's first question relative to the order of check results that may be obtained by this method, I might refer to a test conducted by pouring four molds with aluminum at 800 degs. Cent. (1472 degs. Fahr.) which ran about 23 inches $\pm\frac{1}{2}$ inch in length, and four other molds poured at 750 degs. Cent. (1382 degs. Fahr.) which ran about 15 inches $\pm\frac{1}{2}$ inch in length. This shows fairly well the sensitivity of the method with respect to checking. It also is interesting to note that, for a difference of 50 degs. Cent. (90 degs. Fahr), a difference of about 8 inches in length is noted.

With regard to the second question, whether the difference the metal ran in the mold was due to the percentage of water contained in the sand, our differences were obtained between green sand tempered with 6.5 per cent water and dry-sand molds. It is quite evident that various moisture percentages for green sand should influence the distance the metal would run into the spiral.

Mr. Ward's third question, regarding the ramming of molds, leads me to state that we did not study the effect of the degree of ramming with respect to the distance the metal flowed into the spiral casting.

With regard to the question of permanent molds, we have done no work along this line, as we believe the runability values of the metals

[1] Metallurgist, Chase Brass & Copper Co., Waterbury, Conn.

should be determined on the types of materials used in making the molds in the foundry.

J. T. MACKENZIE:[2] We have had several months' experience now on making this fluidity mold, and our results on pipe iron show a very good correlation. We have not obtained the good checks that the Bureau of Standards has, as our molding technique is not quite as good as theirs; but we have used the same standard and have kept fairly well to the same moisture content.

We did have quite a little difficulty in pouring the molds at first, but now we adopt the practice of using a waste pool just beside the mold. We start pouring into the waste pool and then move the ladle over into the pouring basin, and the results check up very much better.

We have found a very consistent relationship between the temperature of the metal and the length of the spiral. Our data showed a very good relationship between the carbon and silicon and the length of the spiral, all readings being reduced to the same 150 degs. Cent. above the freezing point. Of course, when we go over the line of the eutectic in the gray iron, it will begin to lose fluidity, so our curve shows a maximum fluidity at 4.3 per cent carbon and drops very rapidly for higher carbons.

I believe that every foundryman, with a little practice in pouring, will find it worth his while to put in one of these outfits and experiment with it.

H. M. ST. JOHN:[3] We have been very much impressed, in our experience, with the influence of rather small quantities of impurities on the fluidity of the metal. We do not know as much about it as we would like to know, although we feel convinced that the influence is very considerable. It would be exceedingly interesting to check the effect of various impurities commonly found in brass by the use of one of these boards, which I assume could be done very readily.

The experience that we have had leads us to the conclusion that the maximum temperature reached by the metal does not have any particular influence on the fluidity, but I think it is rather obvious that whether it does or not will depend upon whether the properties of the metal have changed due to the higher temperature reached. In other words, it is a question of the effect of possibly picking up impurities or of chemical reactions that may take place. If the pouring temperature is the same, then the maximum temperature that has been reached by the metal, provided the metal has not picked up any impurities or entered into any kind of a reaction, should make no difference in the fluidity.

This, I might say, is what our experience leads us to believe. We find various things that strongly affect the fluidity of the metal, but the maximum temperature reached does not seem to be one of them. It does not seem to make any difference whether the metal is heated to 2300 degrees and poured at 2100 degrees, or heated to 2200 and poured at 2100, provided the other conditions are kept uniform.

Of course, among the impurities that certainly have an influence,

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[2]Metallurgist, American Cast Iron Pipe Co., Birmingham, Ala.
[3]Chief Metallurgist, Detroit Lubricator Co., Detroit.

sulphur is one. An excess of sulphur certainly makes the metal more sluggish. Metallic impurities—some of them—also certainly have an influence. Phosphorus, as we know, has an influence in increasing fluidity, and some of the other impurities work in the opposite direction.

I believe that the way we are going to get more information is through the use of such a fluidity test as is described in this paper. The Bureau of Standards has provided us with a tool by means of which they, or some of the rest of us who have the time to do it, can get added information.

M. E. BROOKS:[4] With regard to the question asked about how closely brass checks could be obtained, in working with magnesium-base alloys at our foundry we have found that batches of alloy made up to be of the same composition and poured at the same temperature over a period of several months, checked at 1/2 inch. For instance, for one alloy we poured three molds every time, and the fluidity was 16½ to 17 inches every time.

C. M. SAEGER, JR.: We carried out an investigation with the 85-5-5-5 brass composition, studying the effect of maximum heating temperatures. However, an insufficient number of tests have been made and we therefore are unable to draw any conclusions as to whether the increase in the length of spirals cast at a given pouring temperature was due to the maximum heating temperature or to a change in chemical composition. We plan to do further work in this connection. I am very glad Mr. St. John brought out this point.

In studying the design for this method, most all of our work was conducted with a grade of commercially pure aluminum, and further studies were carried out using a brass composition of 85-5-5-5 and cast iron. However, we did not conduct any tests in which we used alloys of aluminum.

H. M. ST. JOHN: It is certainly interesting to hear that the Bureau of Standards is going ahead with this study of impurities. In that connection, the effect of sulphur would be a very interesting problem.

Obviously, in the foundry we always have impurities present in the brass. There are certain impurities always to be found in greater or lesser amount, such as iron, sulphur and two or three others, and the interrelationship between these impurities is, I believe, a very important factor.

One might take absolutely pure metal, add sulphur in varying percentages and determine the effect of sulphur on fluidity, and get certain results. Those results might be (and I believe would be) very different if that metal also contained iron, a little silicon, aluminum, and other things which always are likely to be present.

It would appear, from some work which we have done along this line in a qualitative (not a quantitative) way, that sulphur tends to make the metal more sluggish, if the metal is relatively pure; but in the presence of iron a great deal more sulphur can be added without producing sluggishness.

An analysis of the finished metal to determine the amount of sul-

[4]Metallurgist, Dow Chemical Co., Midland, Mich.

phur present does not tell us what the physical condition of the sulphur is, or how it is combined. If the sulphur is present as copper sulphide, very likely it will have one effect. If it is present as iron sulphide, it may have a very different effect. I presume this has been taken into consideration, but I believe it is a very important point as to the practical application of the results obtained.

I do not want to be misunderstood. A certain alloy poured at 2200 degrees will be more fluid than the same alloy poured at 2100 degrees. However, if one always pours at 2100, my point is that it does not necessarily make any difference how high the metal was heated originally before it was cooled down to the pouring temperature of 2100 degrees. Obviously, if the higher temperature produces a chemical or permanent physical change in the metal, it will have an effect. I am speaking only of cases where no such change takes place.

T. E. KIHLGREN:[5] We have run a number of tests on fluidity, beginning about a year and a half ago, and we have made investigations on several of the common mixtures. We have found fairly good evidence that, on certain mixtures, 0.5 per cent nickel is quite helpful. On the 85-5-5-5 alloy we have found that the same fluidity can be obtained with 0.5 per cent nickel at approximately 75 degrees lower than the same flow without nickel. On one other mixture, a straight gear bronze, 8911, we also found a very definite effect.

These tests were run in this way. On the same day, two 150-lb. pots of metal, one without nickel and the other containing 0.5 per cent nickel, were poured one after the other. We poured ten molds over a range of temperatures beginning with, say, 2450 degrees, right down until it was so cold that the length of flow probably was only one-fourth inch or so. The curves that we obtained by plotting those ten values for each alloy against pouring temperature were generally quite smooth, so that the trend was quite definite.

There are certain mixtures that have not shown any effect at all when using nickel. "G" bronze, for instance, with 0.5 per cent nickel, did not give us any fluidity effect that we could determine. In other words, the length of flow for a given pouring temperature was the same whether nickel was added or not.

We have since tried the effect with 5 per cent nickel on that same mixture, "G" bronze, and it was rather interesting to note that, in spite of the fact that we had raised the pouring temperature some 60 degs. Fahr., the length of flow for any given temperature was the same. That is, one might say that 5 per cent nickel could be substituted for 5 per cent copper to obtain any increased physical values that could be secured without any loss of fluidity.

This finding on the "G" bronze has led us to feel that one other mixture, an 80-10-10 which so far has not reacted to 0.5 per cent nickel, might well be investigated with 5 per cent. We plan to do this very shortly. However, as it stands now we feel that 0.5 per cent nickel very definitely improves the fluidity of red brass and of 89 aluminum gear bronze.

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[5]International Nickel Co., New York.

C. M. SAEGER, JR.: Regarding the runability of virgin metal and remelted metal, we have had indications from our tests that remelted brass, 85-5-5-5, showed greater runability than did virgin metal. I wonder whether this is true in foundry practice.

WM. KELLY:[6] I was formerly with the Cramp Brass Foundry in Philadelphia, and I think that the findings obtained at Washington agree with what we found, that on remelted materials in the nonferrous field the liquidity was better and the casting more satisfactory. I believe that is generally accepted in the foundry.

MEMBER: I made that same point last year in talking about our change from virgin metals to ingot. At that time I asked a question at the round-table discussion as to whether other men had not found that they could pour their ingot metal at a lower temperature than they poured the virgin metal.

While there was not very much agreement, everyone seemed to feel it was the other way around. Nevertheless, we have found from actual practice that we could pour our ingot metal much lower in temperature for the same castings.

I believe the point brought out by Mr. St. John is the answer to this, that they are really not alike; that we have certain impurities in our ingot metal which we do not have, perhaps, in the virgin metal, and which affect the fluidity. However, from the standpoint of actual foundry practice, we find that we can pour the ingot metal considerably lower than we poured the virgin metal.

CHAIRMAN E. R. DARBY:[7] This subject of fluidity is certainly very interesting. It allows us to use restricted gates and still assure ourselves of a full mold, and I believe the Bureau has indicated here a tool which should be used by all of us in our studies of the problems in our own foundries. The question of temperature, or rather, of overheating prior to pouring, may possibly find its effect due to the formation of oxides.

E. C. DOUGHTY:[8] In running the cupola for melting an 85-5-5-5 alloy, we have always found that we get a bad fracture and also gas in the metal if we run the cupola in such a way as to give the metal its maximum temperature.

W. M. BALL, JR.:[9] Does not the duration of the metal in the furnace have a great effect upon the fluidity? If the metal is taken out of the furnace after varying lengths of time, I believe the fluidities should be different, because there is either a loss or absorption taking place all the time the metal is in the furnace, such as the absorption of oxides and also the loss of some of the metals that are present. The alloy is changing. Even in a period of a few minutes it would help to change the fluidity, I believe.

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[6]Research Engineer, Tottenville Copper Co., Tottenville, N. Y.
[7]Chief Metallurgist, Federal Mogul Corp., Detroit.
[8]Chemist, Federal Mogul Corp., Detroit.
[9]Foundry Superintendent, Edna Brass Mfg. Co., Cincinnati.

C. M. SAEGER, JR.: In our preliminary investigation on the runability of metals, we made use of a high-frequency induction melting furnace and we protected the molten metal with a slag. Some analyses of the various heats have been made. However, an insufficient number of analyses have been made to allow me to state at this time just what changes took place.

W. H. SPENCER:[10] We tried the fluidity spiral on cast iron. Knowing that the pouring temperature as well as the composition of the metal would affect fluidity, we first tried pouring the same metal at different temperatures above its freezing point. This test was repeated on other irons, with the results given in Table 5.

Table 5

RESULTS OF FLUIDITY SPIRAL TESTS ON VARIOUS CAST IRONS

Iron No.	Pouring Temperature above Freezing Point. Degs. Cent.	Degs. Fahr.	Length of Fluidity Spiral, in Inches.	Degs. per Inch of Change in Length of Spiral. Degs. Cent.	Degs. Fahr.
1	134	251	6	5.3	9.54
1	150	270	9		
2	97	175	11½	5.6	10.08
2	151	272	21		
3	185	333	36	5.0	9.00
3	150	270	29		
3	99	178	21		
3	51	92	9½		

Iron No. 3 in Table 5, with four spirals poured at different temperatures from the same ladle of metal, gave a change in the length of the spiral of one inch for each 5 degs. Cent. (9 degs. Fahr.) change in pouring temperature, the hotter iron giving the longer spiral. This was in fair agreement with the other two irons on which we had only two tests to the ladle. This temperature effect was for a fluidity spiral cast in green sand, Albany No. 00, with a moisture content of about 9 per cent.

Since it was not always convenient to make a freezing point determination before casting the spiral, we obtained the temperature of the metal as the spiral was cast and determined the freezing point later. The actual length of the spiral under these conditions was measured and corrected for the effect of pouring temperature. All spirals were corrected to the length they would have had if cast at 150 degs. Cent.

[10]Metallurgist, American Cast Iron Pipe Co., Birmingham, Ala.

Table 6

CHEMICAL ANALYSIS, SPIRAL LENGTHS, CORRECTIONS AND OTHER DATA ON IRONS LISTED IN TABLE 5

Si.	S.	Mn.	P.	Total Carbon	Fluidity, in inches. Read.	Fluidity, in inches. Corrected.	Pouring Temp. above Freezing Point, Degs. Cent.	Total Carbon plus 0.3 Si.	Remarks
1.00	0.095	0.47	0.50	3.17	6½	9½	134	3.47	
1.35	0.071	0.48	0.59	3.58	28	19½	193	3.99	
0.95	0.110	0.45	0.38	3.16	9	9	150	3.45	
3.02	0.043	1.38	0.19	2.97	42	22	249	3.88	Ni. 13% Cu. 6%
2.18	0.074	0.52	0.07	2.83	5½	10	128	3.48	
1.45	0.057	0.47	0.70	3.71	22	21	154	4.15	
1.53	0.065	0.48	0.71	3.59	21	21	151	4.05	
2.18	0.069	0.38	0.70	3.51	29	22	185	4.16	
1.10	0.115	0.61	0.07	2.86	6	5	155	3.19	
1.52	0.075	0.52	0.64	3.55	23½	20½	164	4.01	
1.40	0.085	0.59	....	3.55	22	20	159	3.97	
1.38	0.067	0.55	....	3.51	20	19	155	3.92	

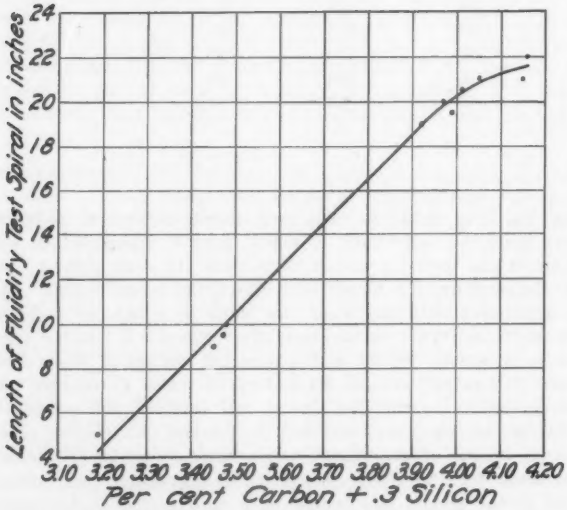

FIG. 13—DATA SHOWN IN TABLE 6, GRAPHED WITH THE CORRECTED LENGTH OF THE SPIRAL PLOTTED AGAINST THE CARBON PLUS 0.3 OF THE SILICON.

(270 degs. Fahr.) above the freezing point of the metal. Five degs. Cent. (9 degs. Fahr.) per inch of length in the spiral was used for correction purposes.

The analysis of the irons used, the spiral length, corrections and other information, are all given in Table 6. This table shows a wide variety of irons; silicon, sulphur, phosphorus and total carbon cover a wide range.

The results from Table 6 are shown plotted in Fig. 13, the corrected length of the spiral being plotted against the carbon plus 0.3 of the silicon. This gives a fairly good curve which seems to flatten at the top. One other test (not shown here), in which graphite appeared on the molten metal and choked the gate, gave only 2½ inches of spiral. This would seem to indicate that the curve would fall violently when that point is reached where graphite in the molten metal begins to interfere with the flow of the fluidity spiral.

Another point worthy of note is that higher phosphorus content lowered the freezing point but did not seem to give any greater fluidity when due allowance was made for this lowering of the freezing point. In other words, the fluidity seemed to depend on the carbon plus 0.3 of the silicon and the amount of superheating, rather than on the phosphorus content.

The high nickel and copper iron gave greater fluidity than other irons of the same carbon plus 0.3 silicon class. However, this metal also had a very large correction and was not plotted on the graph of Fig. 13.

These tests were not conducted without some difficulties. Uniformity of sand and molds, accurate temperature measurements, and other factors must be obtained before consistent results may be expected.

All of this work was carried on as a check on the method of measuring fluidity by means of the spiral. After it was found to be accurate and sensitive, the next object was to find practical application of the spiral test.

For shop control work, where fluidity is a factor, it was found sufficient to pour these spirals at a fixed temperature, preferably at a temperature close to that of the pouring temperature of the casting. The length of the spiral gave directly the fluidity which would exist for that metal in the casting. The spiral could be made, shaken out and observed in time to make corrections either in the composition of the metal or in the pouring temperature of the casting.

The fluidity spirals, made as above, also gave a quick control method for uniformity of composition throughout the heat.

H. M. LANE:[11] Will Mr Spencer tell us with what type of castings he is making use of this fluidity test?

W. H. SPENCER: The type of castings we are using it on consists of pipe and fittings—centrifugal monocast process for pipe, and machine molding on short fittings.

J. T. MACKENZIE: In the 1931 Belgian exchange paper by Dessent

[11]Foundry Consultant, Detroit.

and Kagan on the effect of phosphorus, there are quite a few data on the effect of phosphorus on the fluidity of the iron, showing, for instance, that as the phosphorus is increased from 0.05 to 1.62 the length of the spiral is increased from six numbers to fourteen numbers.

The authors do not take into account, however, the point that Mr. Spencer made, that these readings must be corrected for the freezing point. Thus, a rather spurious increase in fluidity will be attributed to phosphorus.

C. M. SAEGER, JR.: I appreciate Mr. Spencer's remarks. They simply substantiate the efforts we have made. He seems to have found use for the test. I hope that a number of the foundrymen here will be able to construct this same sort of pattern; possibly next year we will then have more to talk about on the subject of fluidity. We believe we now have a method that will tell us something definite, and now we want to find out what fluidity really is.

Report of A.F.A. Committee on Molding Sand Research

Members of the American Foundrymen's Association:

In presenting my report for the year, I desire first of all to call attention to the new and completely revised edition of the A. F. A. booklet on *Testing and Grading Foundry Sands.*[1] This is somewhat larger than the second edition and its compilation involved a large amount of work on the part of the members of the Committee on Tests.

I will refer next to the work of the several committees.

Committee on Tests

Core Tests.

The Sub-Committee on Core Tests has made considerable progress in some directions. During the year the sub-committee members have cooperated in working out the details of a laboratory core-baking oven, and several sample ovens made according to specifications have been placed in operation. The conditions which such an oven should fulfill are described on page 116 of the new pamphlet on tests.

The sub-committee also has done further work on the design of grips for breaking tensile test specimens, and has perfected one of such character that the use of it insures a break through the center of the briquet, even with weak bonded core mixtures. This likewise is described in the new test pamphlet (page 122).

Fineness Test.

It is well recognized that all tests should be so designed that two different operators can check each other on tests of the same material, so that, if there is a difference, it is to be blamed on some other cause than the method.

We have found it difficult sometimes for two persons to check each other on the clay content of a sand, even though each one

[1] Testing and Grading Foundry Sands, new and revised edition. American Foundrymen's Association, March, 1931.

Note: This report was presented before one of the sessions on sand control at the 1931 convention of the American Foundrymen's Association.

Table 1

EFFECT OF DIFFERENT PERCENTAGES OF ELECTROLYTES ON CLAY SUBSTANCE OF ALBANY MOLDING SAND

	Clay Substance, per cent.
No. 1—Regular tap water	12.76
No. 2—Regular tap water plus lime (40 $CaCO_3$ in 100,000)	12.78
No. 3—Regular tap water plus caustic soda (10 parts in 100,000)	12.80
No. 4—Regular tap water plus aluminum sulphate (27 parts in 100,000)	12.66

Table 2

EFFECT OF DIFFERENT ELECTROLYTES ON THE SEPARATION OF CLAY SUBSTANCE FROM THE GRAIN OF MOLDING SANDS

North River (New York)

	Amount of Electrolyte							
	None	25 mg.	50 mg.	100 mg.	200 mg.	400 mg.	800 mg.	1600 mg.
	Per Cent of Clay Recovered							
Sodium hydroxide	13.7	13.8	14.6	14.6	15.5	14.9	15.6	15.4
Sodium oxalate	13.7	13.5	13.4	14.0	14.3	14.0	14.5	14.0
Sodium phosphate	13.2	13.1	13.7	13.6	13.2	14.0	14.8	14.4
Tannic acid	13.2	12.4	12.5	11.7	12.3	12.2	12.1	12.2

Lumberton (New Jersey)

Sodium hydroxide	6.4	7.8	9.9	11.2	11.6	12.0	12.3	12.2
Sodium hydroxide	6.7	6.8	7.6	10.0	10.9	11.1	11.0	11.0
Sodium phosphate	6.7	7.0	7.4	7.3	7.0	7.0	7.2	7.3
Tannic acid	6.4	6.6	5.5	5.4	4.4	4.6	5.0	5.7

Windsor Lock (Connecticut)

Sodium hydroxide	17.1	16.6	18.2	18.2	18.6	18.5	20.1	19.5
Tannic acid	17.4	16.2	17.2	16.9	16.4	15.6	13.8	14.6

Coosada (Alabama)

Sodium hydroxide	16.4	19.0	25.3	34.3	35.6	34.5	34.8	34.8
Tannic acid	16.4			16.6	16.3	16.9		16.6

North River (New York)

	Amount of Electrolyte	
	3 grams	5 grams
	Per cent of Clay Removed	
Sodium phosphate	12.2	12.3
Tannic acid	11.7	11.7

Lumberton (New Jersey)

Sodium phosphate	6.4	6.5
Tannic acid	5.3	5.2

can duplicate his own determination. To illustrate this, duplicate samples of one sand were run by A. A. Grubb at Columbus, Ohio; by W. M. Saunders at Providence, R. I.; by H. Ries at Ithaca, N. Y.; and by M. A. Hosmer at Boston. Tap water was used in each case, and the results of the determination were as follows:

Ries	23.
Grubb	21.4
Hosmer	25.9
Saunders	19.97

Messrs. Saunders and Grubb accordingly came to Ithaca, and we ran four samples of the same sand, again using tap water. The clay determinations ranged from 22.64 to 23.28, showing a maximum variation of only 0.6 per cent. Since we had all three been using exactly the same kind of apparatus, and making the test in the same manner, it seemed quite probable that the alkalinity of the tap water must be at fault, and so samples of water from the three localities were tested, with the result that they showed appreciable difference.

The only way to eliminate this cause of variation would be to use distilled water, and it has been found that this gives better results where comparisons are to be made. In some cases the difference in results between tap and distilled water seemed to be less than in others; in fact, the tap water of any one locality might vary considerably in its alkalinity from time to time. For example, the alkalinity might drop during a period of heavy rainfall and rise during a period of low precipitation. I believe there is no doubt that the tap water may be the cause of these differences.

We have also noticed that a fewer number of siphonings are required with distilled water than with tap water. In one case it was the difference between 6 and 14. Taking 6 minutes for each siphoning, including refilling of the jar, this would mean a saving of 48 minutes, so that the use of distilled water would seem warranted if only for the time saved.

Some sands, however, seem to show little difference when different percentages of electrolytes are used in the water, as the following test by W. M. Saunders, data on which are shown in Table 1, indicates. The experiments were made on Albany sand.

Varying the percentage of electrolyte may materially affect the percentage of clay substance, as the data shown in Table 2, supplied by Mr. Saunders, indicate.

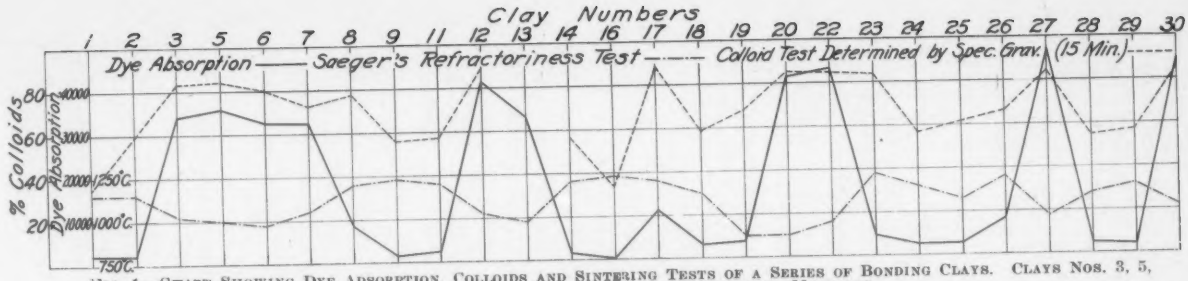

FIG. 1—CHART SHOWING DYE ADSORPTION, COLLOIDS AND SINTERING TESTS OF A SERIES OF BONDING CLAYS. CLAYS NOS. 3, 5, 6, 7, 12, 13, 20, 22, 27 AND 30 WERE BENTONITE MIXTURES.

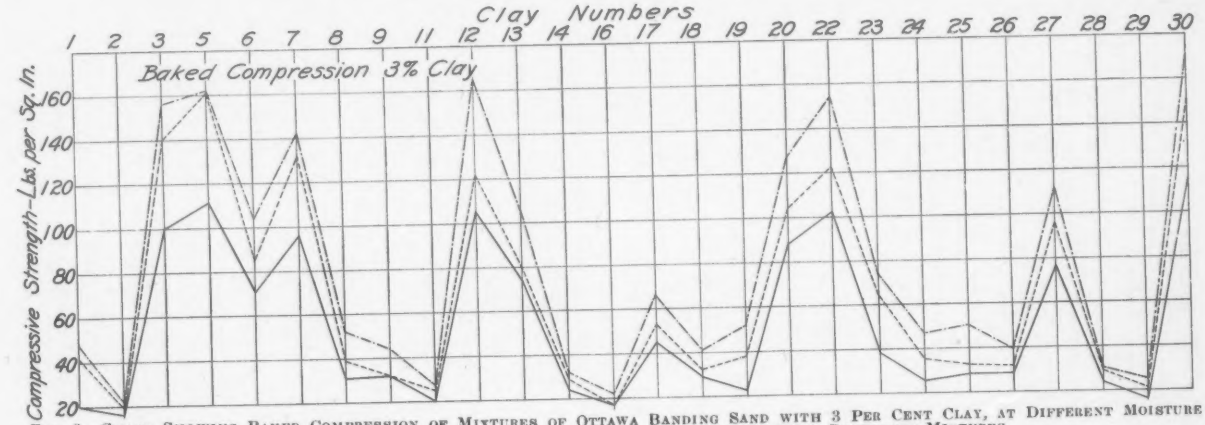

FIG. 2—CHART SHOWING BAKED COMPRESSION OF MIXTURES OF OTTAWA BANDING SAND WITH 3 PER CENT CLAY, AT DIFFERENT MOISTURE CONTENTS. CLAYS NOS. 3, 5, 6, 7, 12, 13, 20, 22, 27 AND 30 WERE BENTONITE MIXTURES.

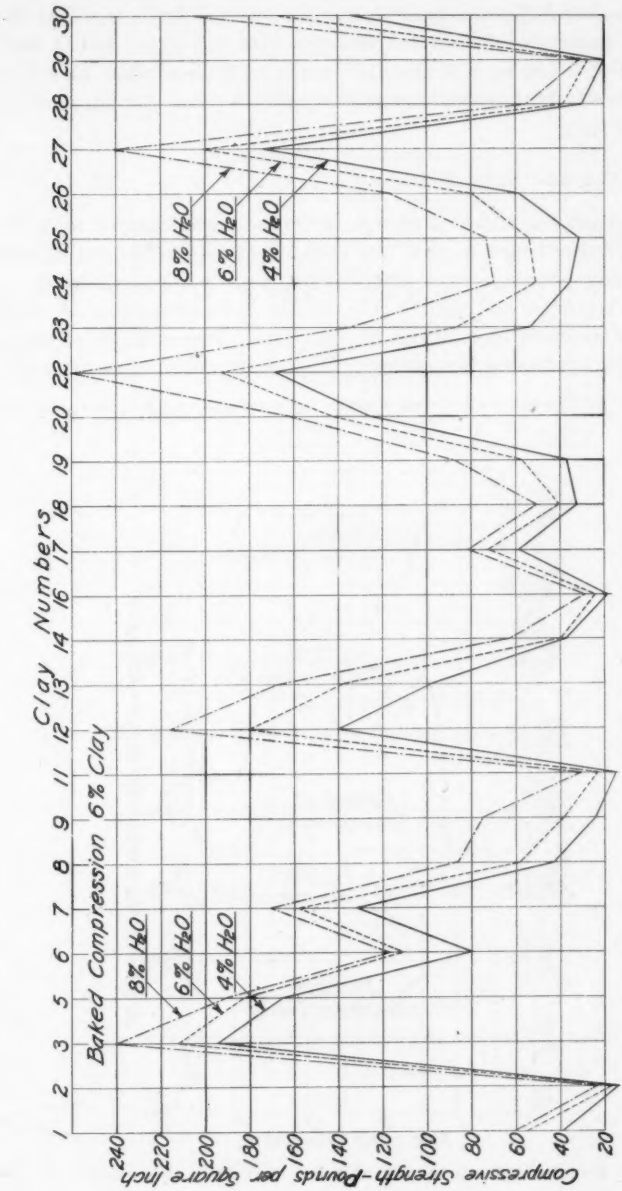

FIG. 3—CHART SHOWING BAKED COMPRESSION OF MIXTURES OF OTTAWA BANDING SAND WITH 6 PER CENT CLAY, AT DIFFERENT MOISTURE CONTENTS. CLAYS NOS. 3, 5, 6, 7, 12, 13, 20, 22, 27 AND 30 WERE BENTONITE MIXTURES.

Another difference noticed, in some cases at least, was that the clay in suspension flocculated strongly with tap water, but showed no sign of doing so with distilled water. *The committee therefore recommends that distilled water should be used for the A.F.A. fineness test.*

Bond Clay and Sand Mixture Tests.

The sub-committee in charge of this test was charged with the duty of suggesting a method that could be employed for testing and comparing bonding clays when mixed with a standard sand.

It reported last year[2] on a rather extensive series of tests which were made on mixtures of sand with different kinds of bonding clays (including bentonites). The sand used in these tests was

[2] *Report of Committee on Standard Tests*, TRANSACTIONS, A.F.A. (1930), vol. 38, p. 481.

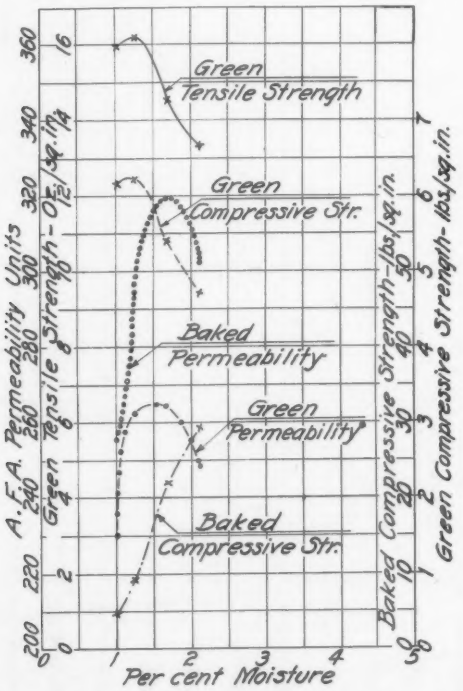

FIG. 4—STANDARD SAND WITH 4 PER CENT NO. 6 BENTONITE.

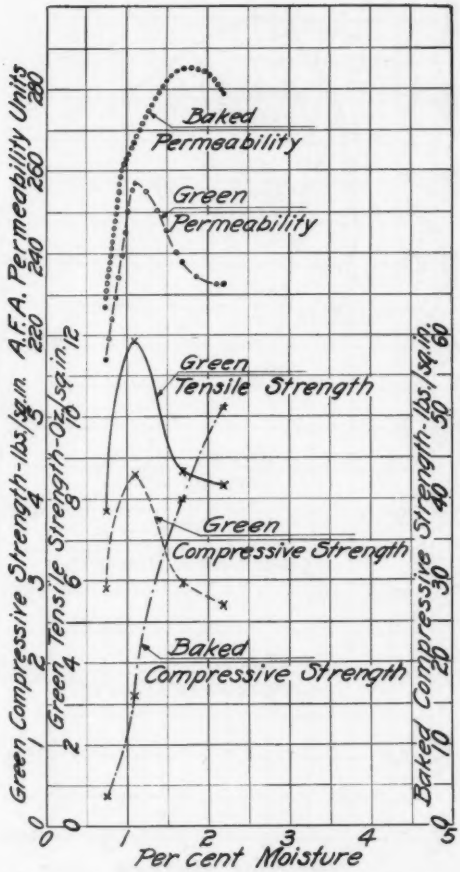

FIG. 5—STANDARD SAND WITH 4 PER CENT NO. 7 BENTONITE.

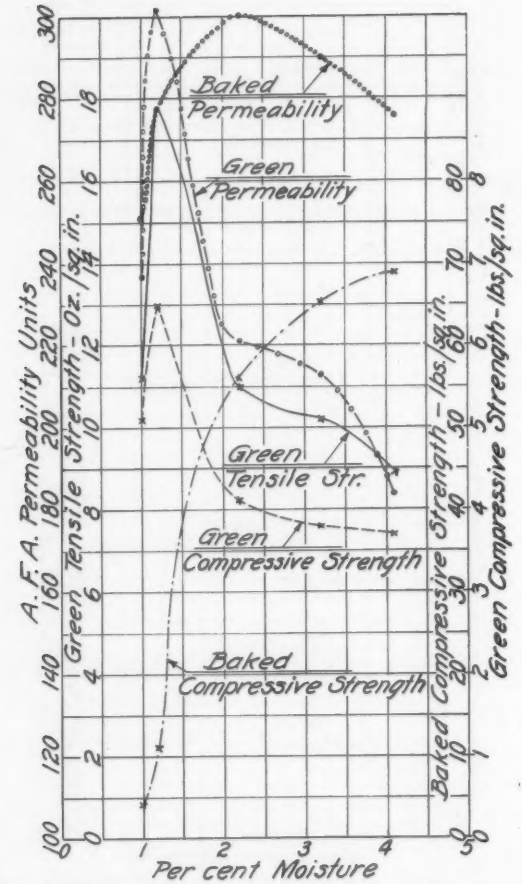

FIG. 6—STANDARD SAND WITH 4 PER CENT NO. 27 BENTONITE.

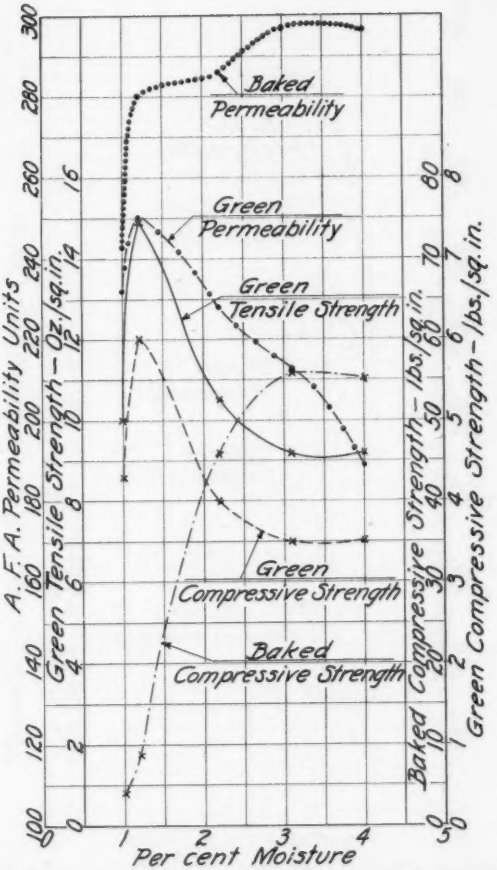

FIG. 7—STANDARD SAND WITH 4 PER CENT NO. 30 BENTONITE.

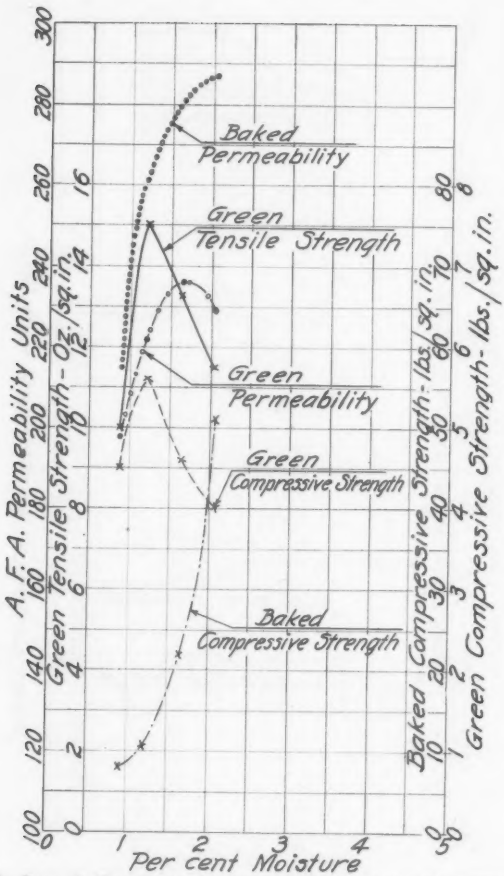

FIG. 8—SAND C (SEE TABLE 3) WITH 4 PER CENT NO. 30 BENTONITE.

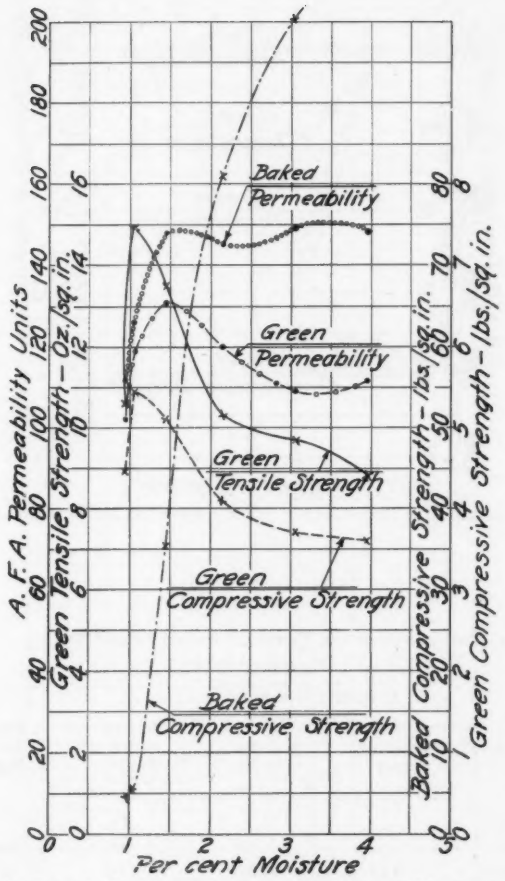

FIG. 9—SAND A (SEE TABLE 3) WITH 4 PER CENT NO. 30 BENTONITE.

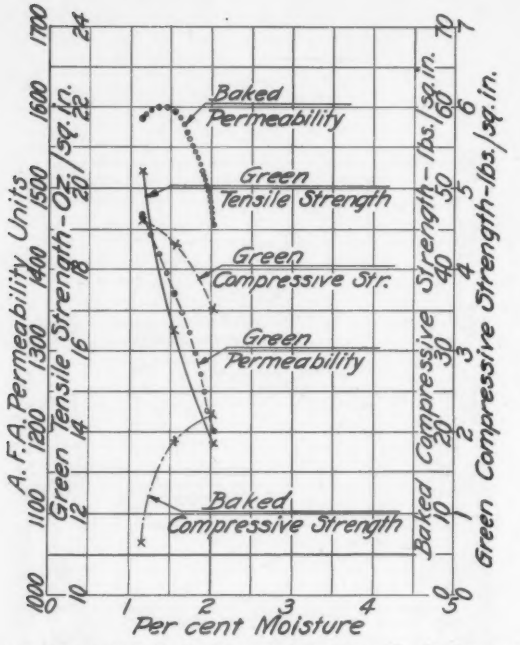

FIG. 10—SAND *D* (SEE TABLE 3) WITH 4 PER CENT NO. 30 BENTONITE.

Table 3

RESULTS OF SIEVE TESTS ON SANDS FROM OTTAWA, ILLINOIS, DISTRICT

Sieve No.	A Banding Sand	B A.F.A. Standard Sand	C Ottawa Silica Sand	D Grade 20-30 Sand
	— Per Cent Grains Remaining on Sieve —			
20	....	0	Tr.	
30	....	.04	.02	(no
40	0.14	.04	.06	sieve
50	3.66	1.52	4.96	test)
70	43.12	96.22	76.86	
100	42.24	2.26	18.08	
140	7.08	Tr.	.06	
200	2.04	0	.02	
270	.90	0	Tr.	
Pan	.48	0	Tr.	

Ottawa banding sand. The mixtures contained 1, 2, 3 and 6 per cent of clay in the case of bentonite, and 3 and 6 per cent of clay in the others. They were all tested with 4, 6 and 8 per cent moisture.

The tests made were green and baked compression, green tension, green and baked permeability, sintering point, dye adsorption, and colloid determination by means of the Bouyoucos specific gravity test. The results of all these tests were set forth by

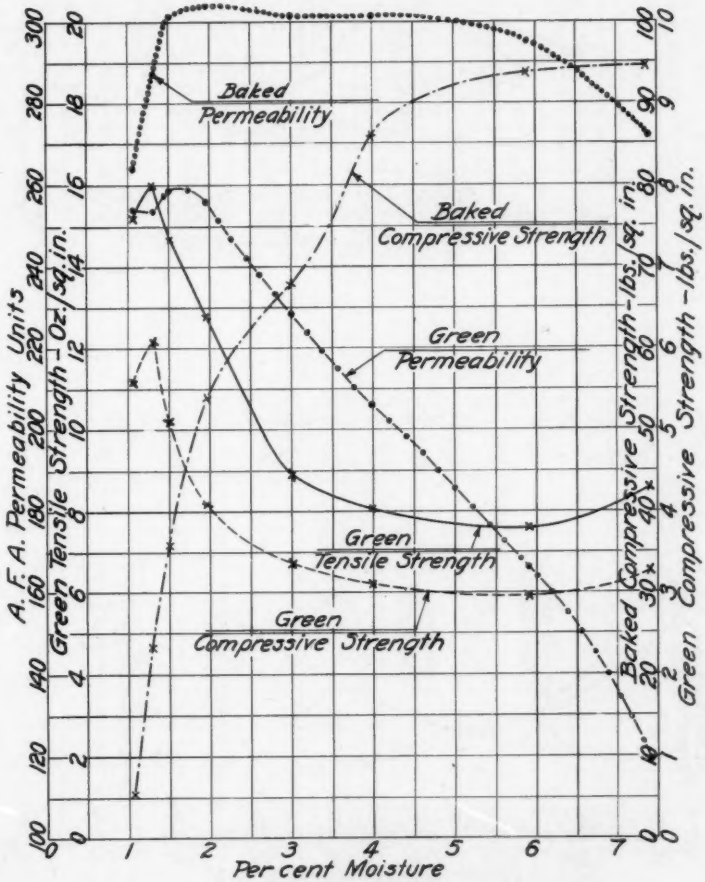

FIG. 11—STANDARD SAND WITH 4 PER CENT NO. 31 BENTONITE.

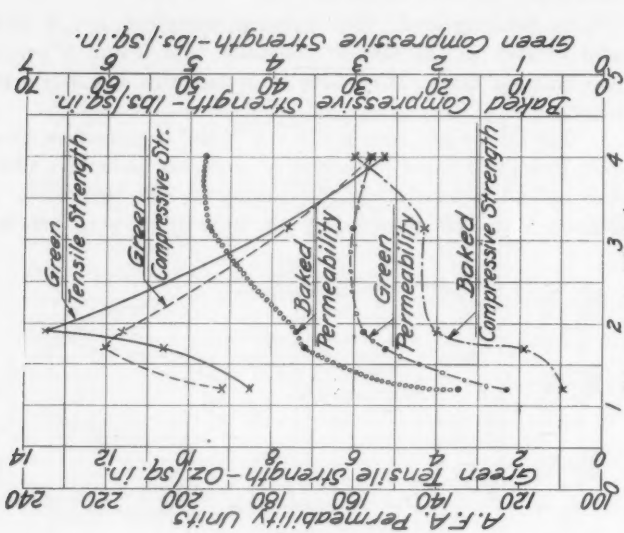

FIG. 13—STANDARD SAND WITH 12 PER CENT NO. 18 FIRECLAY.

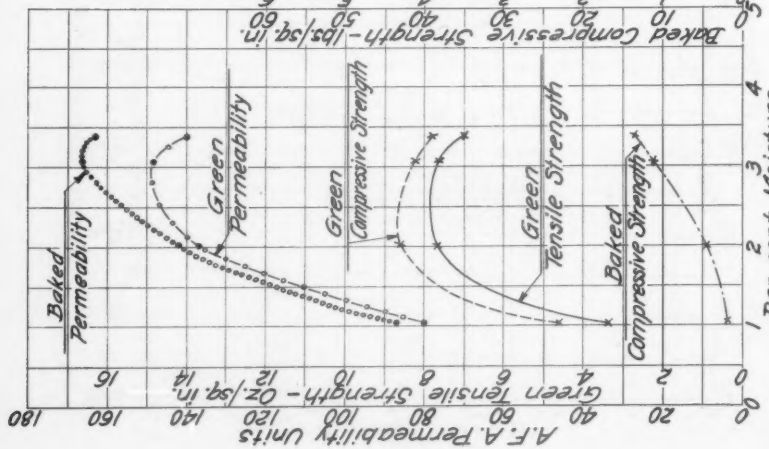

FIG. 12—STANDARD SAND WITH 12 PER CENT NO. 11 FIRECLAY.

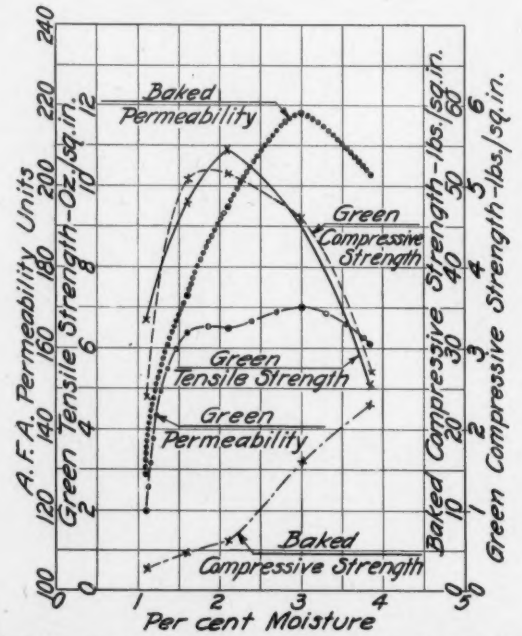

FIG. 14—STANDARD SAND WITH 12 PER CENT NO. 28 FIRECLAY.

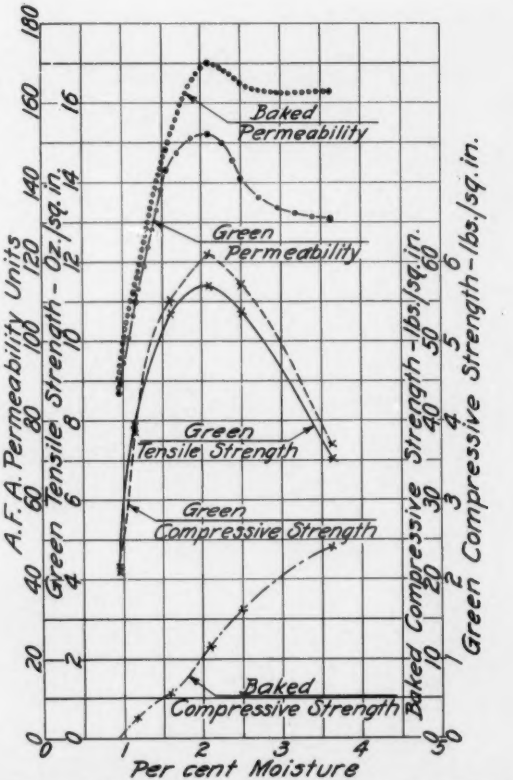

FIG. 15—SAND *C* (SEE TABLE 3) WITH 12 PER CENT NO. 28 FIRECLAY.

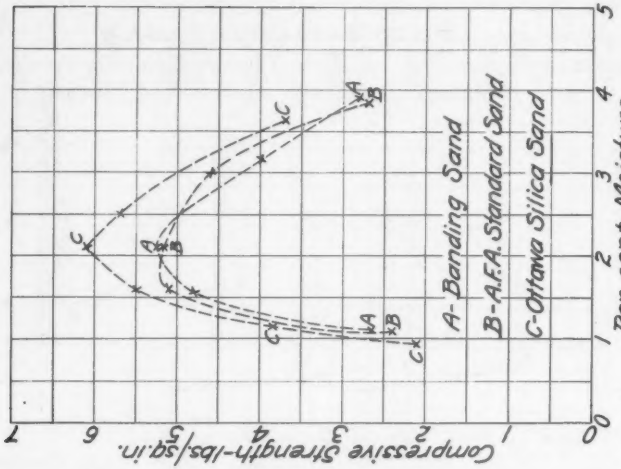

FIG. 17—GREEN COMPRESSION OF NO. 28 FIRECLAY WITH DIFFERENT GRADES OF SAND AS INDICATED BY LETTERS. 12 PER CENT CLAY USED IN MIXTURE.

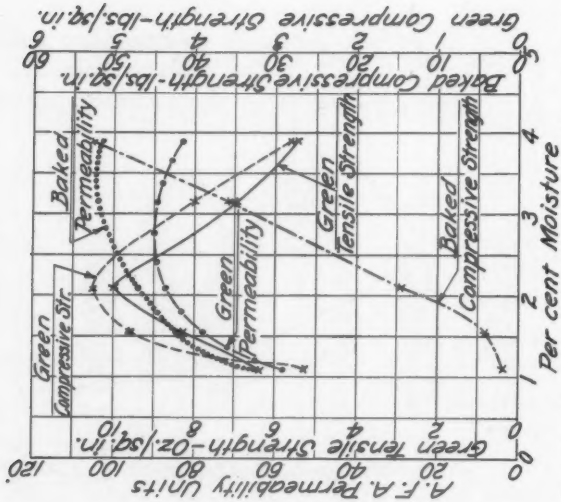

FIG. 16—SAND A (SEE TABLE 3) WITH 12 PER CENT NO. 28 FIRECLAY.

means of graphs, and certain interesting conclusions were drawn from them.

Fig. 1 is of interest as showing the curves of sintering, dye adsorption, and Bouyoucos colloid test.

Figs. 2 and 3 show the baked compression of clays tested last year with 4, 6 and 8 per cent water.

These tests were then supplemented by a second series in which 4 per cent of bentonite was used and 12 per cent of other clays, for the reason that it was thought the two percentages noted above corresponded more closely with the amounts of each type of bond-

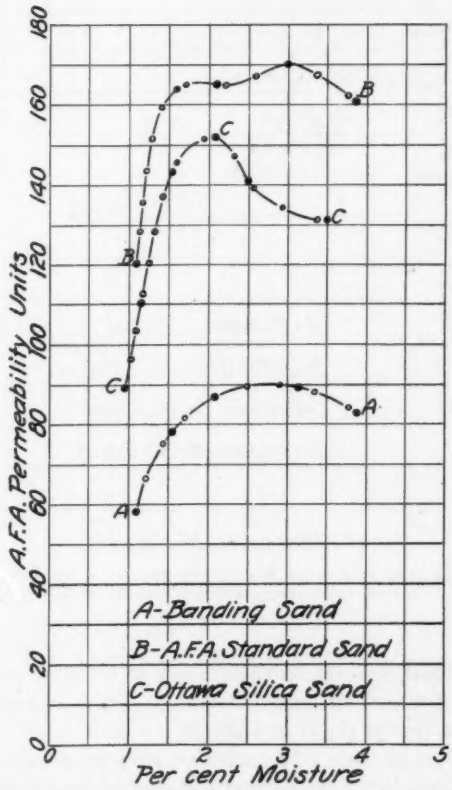

FIG. 18—GREEN PERMEABILITY OF NO. 28 FIRECLAY WITH DIFFERENT GRADES OF SAND. 12 PER CENT CLAY USED.

ing material commonly added to the heap. The moisture percentage used in the second series also was lowered, because it was felt that the previous ones were too high and furthermore that they did not yield a peak for the green strength and green permeability curves.

The graphs shown in Figs. 4-7, inclusive, and 11-14, inclusive, illustrate the behavior of several of the fireclays and bentonites.

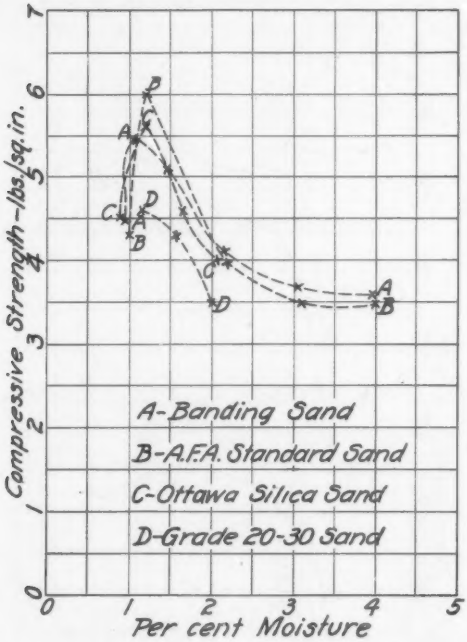

FIG. 19—GREEN COMPRESSION OF MIXTURE CONTAINING 4 PER CENT NO. 30 BENTONITE AND USING DIFFERENT GRADES OF SAND.

In addition, several of these clays were tried with sands of other grain fineness, all from Ottawa, Ill., those employed showing the sieve test results given in Table 3.

The curves of Figs. 7-10, inclusive, give the results obtained on No. 30 bentonite with the different grades of sand shown in Table 3. Figs. 14-16, inclusive, give the results of a similar set of tests

made with No. 28 fireclay. Fig. 17 shows the green compression of No. 28 fireclay with different grades of sand. Fig. 18 shows the green permeability of No. 28 fireclay with different grades of sand. Fig. 19 compares the green compression alone of No. 30 bentonite with different grades of sand, while Fig. 20 compares the green permeability.

It will be noticed, in these four cases, that there is not much

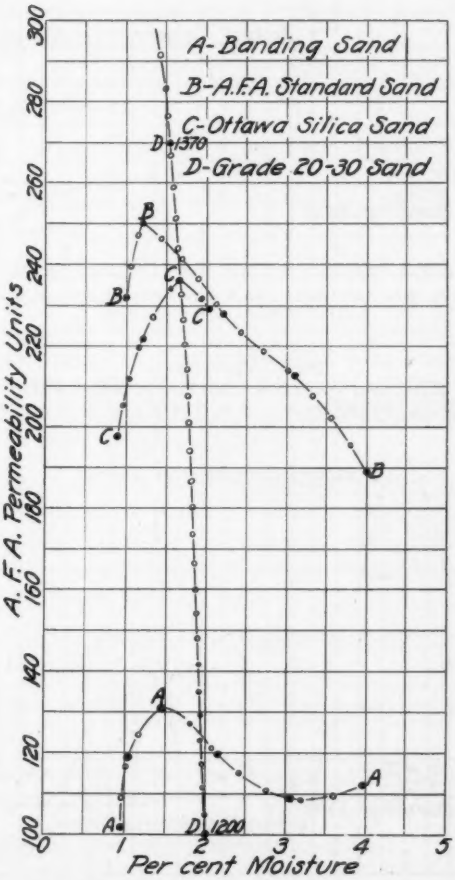

FIG. 20—GREEN PERMEABILITY OF MIXTURE CONTAINING 4 PER CENT NO. 30 BENTONITE AND USING DIFFERENT GRADES OF SAND.

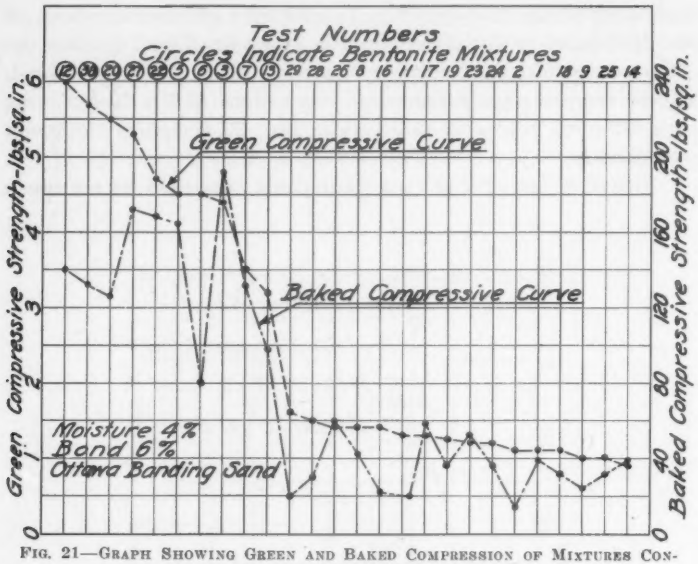
Test Numbers
Circles Indicate Bentonite Mixtures
12 30 20 27 22 5 6 3 7 13 29 28 26 8 16 11 17 19 23 24 2 1 18 9 25 14
Green Compressive Curve
Baked Compressive Curve
Moisture 4%
Bond 6%
Ottawa Banding Sand
Green Compressive Strength-lbs./sq.in.
Baked Compressive Strength-lbs./sq.in.
0 1 2 3 4 5 6
0 40 80 120 160 200 240

FIG. 21—GRAPH SHOWING GREEN AND BAKED COMPRESSION OF MIXTURES CONTAINING 6 PER CENT BOND CLAY.

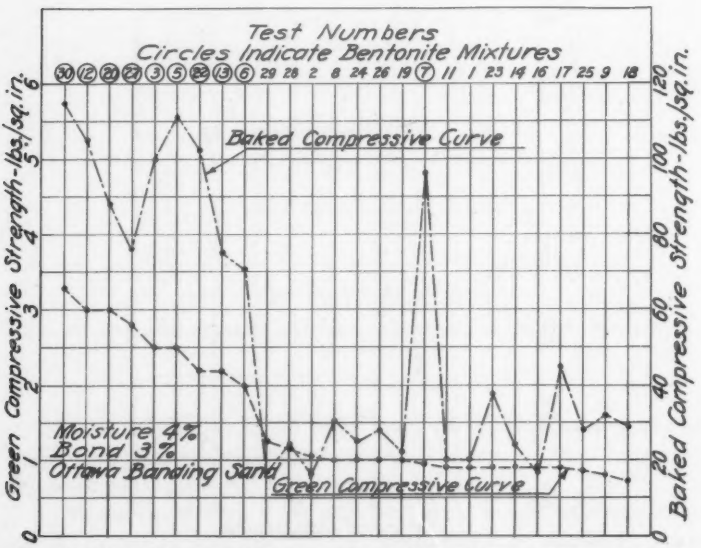
Test Numbers
Circles Indicate Bentonite Mixtures
30 12 20 27 3 5 22 13 6 29 28 2 8 24 26 19 7 11 1 23 14 16 17 25 9 18
Baked Compressive Curve
Moisture 4%
Bond 3%
Ottawa Banding Sand
Green Compressive Curve
Green Compressive Strength-lbs./sq.in.
Baked Compressive Strength-lbs./sq.in.
0 1 2 3 4 5 6
0 20 40 60 80 100 120

FIG. 22—GRAPH SHOWING GREEN AND BAKED COMPRESSION OF MIXTURES CONTAINING 3 PER CENT BOND CLAY.

horizontal shifting of the peaks, but it is greater for the permeability than for the compression.

A further tabulation of the clays tested last year was made to show the relation between green and baked compression. Figs. 21 and 22 show the results of these tests and indicate no direct relationship.

Recommended Method for Testing Bonding Clays

The committee recommends the following method for testing bonding clays:

1—For testing and comparing bonding clays, the A.F.A. standard sand shall be used.

2—For testing bentonite, 4 per cent is to be added to the mixture.

For testing other clays than bentonites, 12 per cent is to be used in the mixture.

3—Mixtures shall be made up with a water content ranging from 1 to 4 per cent. If the curve of green properties when plotted does not show a peak with moisture percentages represented by a whole number, then intermediate half percentages should be tried between those whole numbers where the peak appears to lie.

It is realized that the optimum water content may not represent the best working condition.

4—The sand and clay shall be mixed 3 minutes dry, mulled 5 minutes dry, and then 5 minutes wet after adding the necessary amount of moisture. About 0.25 per cent excess moisture should be added. The mixing pan should be covered while the wet mulling is going on, to prevent moisture loss.

5—Remove the mulled sand from mixer, *not* including that adhering to the sides of the pan.

6—Transfer the mixture to sealed jars and allow to stand for 24 hours.

7—Remove mixture from jar, pass through ¼-inch riddle and return to jar.

8—Take sample for moisture determination.

9—The sand is then to be tested for green compression, green permeability, and green tension, all tests being run in triplicate.

10—Ram up three cores in sand container, strip, and place in oven for 2 hours at 150 degs. Cent., for baked compression test.

Ram up three more cores, leave in sand container, and bake for 2 hours at 150 degs. Cent. for baked permeability test.

11—The baked specimens are to be placed in dessicator over sulphuric acid until cool, when they are to be tested.

12—A sintering test can be made if desirable or necessary.

Comments

Whether the sand is to be tested in both green and baked condition may depend on whether it is to be used for green or dry sand molding.

Some foundrymen might desire to test the sand at only the moisture content used in their heaps.

It is recognized also that a foundry might desire to use the sand commonly employed at the plant.

The committee believes, however, that for purposes of comparison standard sand should be used in all cases.

TERMS USED IN FOUNDRY SAND WORK

There are a variety of terms used in foundry sand work, which relate to materials, tests and properties. Many of these terms have at times been loosely used, and it seemed desirable to prepare proper definitions, which would indicate clearly what they refer to.

The Sub-Committee on Terms accordingly has prepared a series of foundry terms with their definitions, which are given below. This list has been somewhat widely circulated for criticisms and suggestions, and those received have been quite helpful. Additions to the list will be made from time to time.

Certain materials like sand, clay, gravel and loam are used in several different industries, and it would be highly desirable if a joint committee of these industries could agree on a common form of definition for those materials used by all of them.

Definitions of Foundry Terms, suggested by Sub-Committee on Terms

BAKED PERMEABILITY. (See *Permeability.*)

BAKED STRENGTH. (See under *Strength.*)

BASE PERMEABILITY. (See under *Permeability.*)

BOND, BONDING SUBSTANCE, BONDING AGENT. Any material other than water which, when added to foundry sands, imparts bond strength to them.

BONDING CLAY. Any clay suitable for use as a bonding material.

CLAY. Inorganic earthy material which becomes more or less plastic and sticky when wet, and dries to a fairly hard and rigid mass.

CLAY SUBSTANCE. That earthy portion of foundry sand which, when suspended in water, fails to settle one inch per minute, and which is more or less plastic when wet.

COLLOIDS, COLLOIDAL MATERIAL. Finely divided material less than 0.5 micron (0.00002 inch) in size, gelatinous, highly adsorbent and very sticky when moistened.

COMBINED WATER. That water which is driven off only at temperatures above 110 degs. Cent. (230 degs. Fahr.)

COMPRESSIVE STRENGTH. (See under *Strength.*)

CORE SAND. A sand that is suitable for making cores; it is usually low in clay substance.

DRY FINENESS. The fineness of a sample of foundry sand, from which the clay has not been removed, and which has been dried at 105 to 110 degs. Cent. (221 to 230 degs. Fahr.)

DRY PERMEABILITY. (See under *Permeability.*)

DRY STRENGTH. (See under *Strength.*)

FINENESS. The extent of subdivision of a foundry sand, as determined by the A.F.A. fineness test.

FINE SILT. Earthy materials which, when suspended in water, fail to settle one inch per minute, but which are not plastic or sticky when wet.

FLOW, FLOWING QUALITY. The mobility of a foundry sand by virtue of which it fills the recesses and moves against pattern surfaces not necessarily in the line of squeezing or ramming force.

GRAIN. The granular material, of molding or core sand, left after removing the clay substance in accordance with the A.F.A. fineness test.

GRAVEL. The granular material resulting from the natural or artificial disintegration of rock and characterized by an appreciable proportion of particles that would pass a sieve with one-half inch opening and remain on a No. 6 sieve. A gravel may contain considerable quantities of coarser and finer particles.

GREEN PERMEABILITY. (See under *Permeability.*)

GREEN SAND. Sand containing moisture or other liquid.

GREEN STRENGTH. (See under *Strength.*)

LOAM. A mixture of sand, silt and clay particles in such proportions as to exhibit sandy and clayey particles in about equal proportions. It is roughly 50 per cent sand, and 50 per cent silt and clay.

MOISTURE, TEMPER WATER. Water which can be driven off by heating at 105 to 110 degs. Cent. (221 to 230 degs. Fahr.)

MOLDING SAND. A sand that is suitable for making molds in which metals can be cast successfully.

PERMEABILITY. The rate at which a molded mass of sand permits gas to pass through it.

BAKED PERMEABILITY. The permeability of a molded mass of sand baked at a temperature higher than 110 degs. Cent. (230 degs. Fahr.)

BASE PERMEABILITY. The permeability of dry sand grain containing no clay substance.

DRY PERMEABILITY. The permeability of a molded mass of sand dried at 105 to 110 degs. Cent. (221 to 230 degs. Fahr.)

GREEN PERMEABILITY. The permeability of a molded mass of sand while tempered.

POROSITY. The volume of pore space or voids in a sand.

SAND. The granular material resulting from the natural or artificial disintegration of a rock, a predominant proportion of which passes the No. 6 sieve and is retained on the No. 270 sieve. A sand may contain considerable quantities of larger or smaller particles, including clay.

SHARP SAND. A sand whose particles are largely angular.

SHEARING STRENGTH. (See under *Strength.*)

SILT. Very fine sand particles that pass a No. 270 mesh sieve, but which are not plastic or sticky when wet.

STRENGTH:

BOND STRENGTH. That property of foundry sand by virtue of which it offers resistance to deformation.

BAKED STRENGTH, BAKED BOND STRENGTH. The resistance which a molded specimen of sand offers to deformation when baked at any temperature above 110 degs. Cent. (230 degs. Fahr.)

COMPRESSIVE STRENGTH. The maximum resistance which a molded specimen of sand offers to a compressive stress.

DRY STRENGTH, DRY BOND STRENGTH. The maximum resistance which a molded specimen of sand, dried at 105 to 110 degs. Cent. (221 to 230 degs. Fahr.), offers to an applied stress before it breaks.

GREEN STRENGTH, GREEN BOND STRENGTH. The resistance which a molded specimen of sand, while tempered, offers to an applied stress before it breaks.

SHEARING STRENGTH. The maximum resistance which a molded specimen of sand offers to a shearing stress.

TENSILE STRENGTH. The maximum resistance which a molded specimen of sand offers to a force which tends to pull it apart.

TRANSVERSE STRENGTH. The maximum resistance which a molded specimen of sand offers to a transverse stress.

TEMPER (*noun*). The condition of sand with respect to molding properties that is due to its moisture or other liquid content.

TEMPER (*verb*). The process of mixing sands with sufficient water or other liquid to develop its molding properties.

TENSILE STRENGTH. (See under *Strength.*)

TRANSVERSE STRENGTH. (See under *Strength.*)

VENTING QUALITY. (Same as *Permeability.*)

Durability of Sands.

The durability test is an important one which still remains to be developed. The sub-committee in charge of this has formulated a method for testing this property, but recommendations will not be made until there has been opportunity to study the method in detail. Plans had been made, whereby a careful sudy of the method could be conducted at a large foundry in cooperation with the foundry department of a nearby university, but at the last minute it was found that the investigation could not be carried out. It is hoped that other plans leading toward the desired end can be completed in the near future.

GRADING COMMITTEE

The Committee on Grading has been considering methods for calculating and expressing grain distribution. Several methods were proposed about four years ago, and of these, the Tyler graphic method and a Calculative method were given a great deal of study

and investigation. These two methods were fully described in previous reports[5, 6] of the Committee on Grading.

The major points of difference between the two methods that were considered are as follows:

(1) The Tyler method is largely graphic. The fineness data are put into cumulative form and plotted on a special print of chart paper. The other method is purely calculative; it is an outgrowth of and is similar to the standard method for calculating grain fineness.

(2) The Tyler uniformity coefficient is determined by two and only two points on the fineness curve. Shifts in grain distribution that do not affect these two points, are not registered in the coefficient. By the calculative method every fraction of sand grain —the entire fineness curve—is registered in the coefficient.

(3) A coefficient that is established by graphic means may be varied somewhat in the process of charting, thus permitting a possible argument as to its exact value. A purely calculative method established its result very definitely.

(4) The Tyler method is at present in use to some extent for measuring the grain distribution of filter sands. The calculative method is entirely new.

After investigating and considering these matters at length, a vote was taken in February of the present year. The calculative method was recommended without a dissenting vote. It yields an index figure that is to be called the Distribution Coefficient.

Two calculative methods are under consideration by the committee. One of these was described in the A.F.A. *Transactions and Bulletin* for October, 1930; the other is presented at this session. The committee has not yet decided which is the better of the two.

USE OF TESTING APPARATUS

The Committee on Tests again wishes to urge that all testing apparatus should be kept in proper condition, otherwise it cannot be expected to give accurate and consistent results. Many complaints regarding apparatus have been investigated by the committee, and in practically every case the trouble has been traced

[5] *Report of Committee on Grading*, TRANSACTIONS A.F.A. (1927), vol. 35, pp. 187-198.

[6] *Report of Committee on Grading*, TRANSACTIONS A.F.A. (1930), vol. 38, pp. 510-515.

either to improper care of the apparatus or to neglect to observe the rules for operating the equipment.

In conclusion, I think we can feel that something has been accomplished during the past year, and that the sand research work, insofar as it concerns the development of standard tests, may be regarded as well along toward completion, although work still is to be done looking toward the simplification and improvement of some tests.

Too much cannot be said in appreciation of the whole-hearted way in which the members of the several committees have worked and cooperated. Without their assistance, unselfishly given, little would have been accomplished.

Respectfully submitted,

H. RIES,

Technical Director.

DISCUSSION

H. M. LANE:[1] In regard to the use of distilled water in the fineness test, a good many years ago, on some research work, I had several cases where real trouble occurred in the strength of cores. In one case the foundry had two wells as a source of water. For some time all the core-room water had come from the shallow well, and all was well with the core strength. Later, water was used from a deep well, the water being highly mineralized, and trouble occurred.

They immediately condemned the core oil, saying it was no good. What had happened, however, was that the deep-water well was so highly mineralized that it was saponifying the oil and destroying its bonding power, this being the cause of the trouble.

In another case where we had trouble with core strength, we went to cistern water and rain water and did a number of things of that kind to clear up the trouble.

MEMBER: What was done with regard to the sand-strength machine where the speed of operation was controlled?

DR. H. RIES:[2] Some years ago, when the committee was considering strength tests of sand, they recommended that the compression test be adopted as the standard, although that did not prevent persons from using shear or other strength tests if they so desired. At that time we carried out a number of experiments with different types of machines, in which we varied the rate of application of the load, and we found that

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[2]Professor of Geology, Cornell University, Ithaca, N. Y.

it made comparatively little difference whether the load was applied rather rapidly or fairly slowly—I will not say with excessive speed or excessive slowness. The standard recommendation now is that the load be applied at the rate of about 30 lbs. per minute.

We did find, as I say, that the rate of application of the load could be varied appreciably without affecting the result very much, and we worked that out on three or possibly four types of machines.

CHAIRMAN R. F. HARRINGTON:[3] I think the member who has just spoken would like to leave to the committee the investigation as to whether or not the speed of loading affects the various strengths.

L. B. KNIGHT:[4] By changing the application of the load, one can get almost any strength desired, within limits. I believe that is one reason why Mr. Dietert put a motor on his latest machine, in order to eliminate that human error. In the Adams machine, no matter how fast it is loaded there will be no appreciable variation in the strength; but on some of the shear machines, and on the dead-weight machine, if the rate of application of the load is varied there will be a variation in the strength.

C. E. JACKSON:[5] In regard to the question about the speed of loading the compression machine, part of the investigational work was done at the Bureau of Standards. The apparatus was set up in a drill press, and absolute control of the speed of the load was taken. No appreciable change showed up in the test; there was no noticeable variation in the strength. The machine used was the spring compression machine.

A. A. GRUBB:[6] I think it might be well at this time to call your attention to one frequent source of error in making permeability or strength tests. If the standard A. F. A. rammer is used and the weight is lifted carelessly—lifting the rammer rod a little and then letting it fall—an extra heavy blow will be struck. If the specimen is rammed harder, higher strength test and lower permeability test results will be obtained.

On the other hand, if the weight is lifted and the hand is allowed to follow down with it part way as it falls, the results can be varied as much as fifty per cent.

This is one of the most frequent sources of error. Caution your operators to be very careful to lift the weight up against the upper stop and then to remove the hand from it in a horizontal or upward direction, letting the weight fall the entire distance and only the entire distance.

Carelessness in this respect not only affects the permeability of the sand but it is making serious trouble for the producers of sand. Some sand producers refuse to talk permeability because of the variations in the tests, and sometimes we cannot blame them.

DR. H. RIES: There is another point to be considered, and that is the character of the surface on which the rammer is resting. It should be a solid surface, for if there is any spring to it, another variation will be obtained in the result.

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[4]National Engineering Co., Chicago.
[5]Scientific Assistant, U. S. Bureau of Standards, Washington.
[6]Grubb & Marshall, Columbus, Ohio.

Foundry Refractories

By Jas. R. Allan,* Chicago

Abstract

Standards for shapes of malleable furnace refractories have been approved, although some foundries still use shapes other than standard. A wide variety of shapes calls for greater production costs. A probable contributing cause of the variety of shapes being used is considered to be the variation in tolerances of fireclay shapes. Tight clay joints are shown to increase the refractory life, as does eliminating the number of joints. Close tolerances permit closer joints and less cost of lining. Present manufacturing tolerances are listed and proposed new tolerances advocated. A survey of sixteen brands of 9-inch straight brick shows a wide variation in sizes in a few brands. The use of the "brick meter" for measuring brick is advocated.

1. Foundry refractories is an important subject that has received much attention for a number of years from the American Foundrymen's Association's Committee on Foundry Refractories. Most of this committee's activities have been in conjunction with the Joint Committee on Foundry Refractories.

Standards for Malleable Furnace Shapes

2. Some constructive work has been accomplished. For instance, malleable foundry firebrick shapes were standardized in 1928, with the issuing of recommendation R-79 by the U. S. Bureau of Standards, Division of Simplified Practice. In these standards the prime purpose was, of course, to eliminate the many varieties of bung brick and tap-out blocks, and to standardize on shapes that were practical.

3. Many refractory producers still report some malleable

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Note: This paper was presented as the report of the Committee on Foundry Refractories, before the 1931 convention of the American Foundrymen's Association.

foundries ordering bung and tap-out shapes other than standard. This practice works a hardship on producers of refractories because it means the making of special molds, carrying stocks in inventory which are infrequently called for and for which, in many cases, higher prices must be asked.

4. Let us emphasize that the refractory producer's problem is identical with the foundryman's problem when a great many patterns are placed in the sand and only a few castings are required of each. Who pays the bill? The casting user, of course.

5. We also call attention to the persistence of some foundries in still ordering the 13-inch length series of bung brick. If those foundries which still adhere to the 13-inch lengths would only analyze the disadvantage of the 13-inch series and the advantage of the 13½-inch series that are now standard, there would be no need for supplying the off-standard shapes.

6. Possibly one or two additional shapes should be added to the list of standardized malleable shapes, but we have felt that there has been a growing adherence to the new standards and that eventually there will be little need for adding more variety.

Lack of Tolerances Possible Cause of Variety of Shapes

7. Possibly one of the contributing causes of numerous varieties of shapes has been the lack of reasonable tolerances on fire clay shapes. For some time the Committee has been advocating much closer tolerances, with the result that many progressive refractory producers are giving this subject a great deal of attention.

8. The writer, as representing the A. F. A., presented data showing the need for closer tolerances in firebrick shapes for the foundryman at the symposium on refractories held in February, 1931, by the American Ceramic Society. The producers' representatives at this symposium indicated by the tenor of their papers that definite attention was being paid to the subject and that better conditions would eventually come about. The need for close tolerances may best be presented by abstracting our report at the recent symposium.

9. Refractory producers are endeavoring at all times to grade up the refractory qualities of brick, but additional operating economies to foundries can be had by manufacturing firebrick shapes to much closer tolerances.

Melting Furnace Gives Severest Use

10. Foundry melting equipment accounts for the most severe usage to which refractories are put. This is occasioned by the very nature of the firing, charging and handling methods employed. Unlike other heat equipment, melting equipment requires frequent repairs and renewals of refractories.

11. These are expensive operations in labor, brick, clay and cement. The limited time allowed for making such repairs does not permit selecting and sorting brick for size and shape, grinding and rubbing joints and other expedients resorted to in more permanent brick jobs.

Fireclay Joints Important

12. When brick are laid in ordinary fireclay, the clay joints are the first to fail, either by crumbling or fusing away, because the fusion point of plastic fireclays is considerably below that of the brick. The thicker the brick joints, because of poor bricklaying or of considerable variation in brick sizes, the greater the tendency to earlier failure.

13. An obvious recourse would be to lay up the brick dry and eliminate the plastic clay joint. Actual experience indicates that brick joints must be protected with a clay or cement to prevent the penetration and progress of heat, flame, metal and slag.

Survey of Effect of Clay Joints on Life of Refractories

14. A survey of reverberatory melting furnaces indicated that fireclay joints increased the life of refractories as follows:

> Fire-box side-walls, 88 per cent; furnace side-wall, 14 per cent; fire-box bungs, 30 per cent; charging bungs, 25 per cent; rear bungs (which generally give long service), 5 per cent.

15. In order to improve brick-work joint efficiency, it is necessary to have joints as thin as possible so that early joint failure will not occur. This can be accomplished only when brick can be had to closer tolerances and the old-fashioned brick layer with his trowel is eliminated.

16. High-grade plastic clays and high-temperature furnace cements can be justified only generally in furnaces if brick come to close limits of tolerance in order to reduce the quantity of clay

and cement required for 1000 brick. High-grade fireclays cost two to three times as much as ordinary fireclay, and the cement costs about fifteen times as much.

Reducing Number of Joints Increases Service

17. Further to prove that brick joints are a cause of failure, certain experiments are going on, using special large-size brick that reduce the number of joints 27 per cent, with a 15 per cent increase in service life. Experiments with various types of industrial furnaces, selecting brick for uniformity and laying in high-temperature furnace cement, show an increase in service life of from 5 to 25 per cent.

Close Tolerances Permit Better Life of Refractories

18. If firebrick producers will produce brick to closer tolerances, we should expect at least a 10 per cent increase in service life of refractories. In addition to this increase in life, less clay will be used for the joints and brick laying labor will be reduced considerably. A foundry that has recently been giving serious attention to its refractory costs has determined that it was getting better service life from brick true to shape and size. After trials with many brands of brick, it eliminated all brands with the exception of the one that seemed to have a minimum of variation.

19. We witnessed a test of assembling seven bungs with No. 105 13½-inch bung brick, each bung frame containing 43 brick. The cracking and breakage on tightening the bung clamps were 1-8-3-1-4-2-10, a total of 29 brick out of 301, which meant approximately 10 per cent broken bricks.

20. This was not a bad average, because broken and cracked bricks in bungs may run as high as 20 to 45 per cent. However, cracked bung bricks mean just so many more unprotected joints that eventually induce earlier failure.

21. There is a tendency for many brands of brick to run undersize in volume. Adhering to close tolerance on brick on the standard dimensions will mean that the consumer will receive more volume or weight, which is easily translated into longer service life because of more material.

22. One very important advantage with close tolerances on dimensions of firebrick is that the large consumer can stock several

brands of brick and be able to use them in the same job. Experience has shown that there are more or less consistent variations that are peculiar to each brand of brick, which prevent mixing of brands.

Standards for Tolerances in Sizes

23. The manufacturing tolerances now in effect and adhered to by the firebrick producers are plus or minus 2 per cent on dimensions of 4 inches or over, and 3 per cent plus or minus on dimensions under 4 inches. These present tolerances are very great if we stop to think that the tolerance on a 13½-inch dimen-

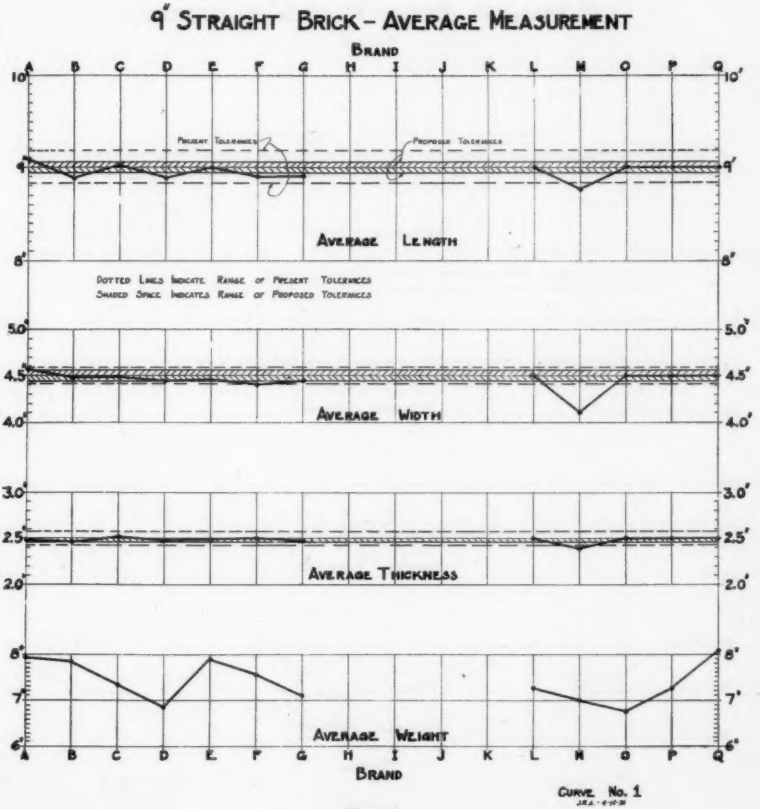

FIG. 1.

sion on bung brick is plus or minus 0.27 inch, and is plus or minus 0.18 inch on 9-inch dimensions, 0.09 inch plus or minus on 4½-inch dimensions, and 0.075 inch on 2½-inch face dimensions.

24. Our committee has been advocating the adoption of the following tolerances on all standard fire-clay shapes of all qualities and for all purposes:

On length dimensions, plus or minus..1/16 or 0.0625 in.

On width dimensions, plus or minus..1/16 or 0.0625 in.

On face thickness dimensions, plus 0
minus .....3/64 or 0.046875 in.

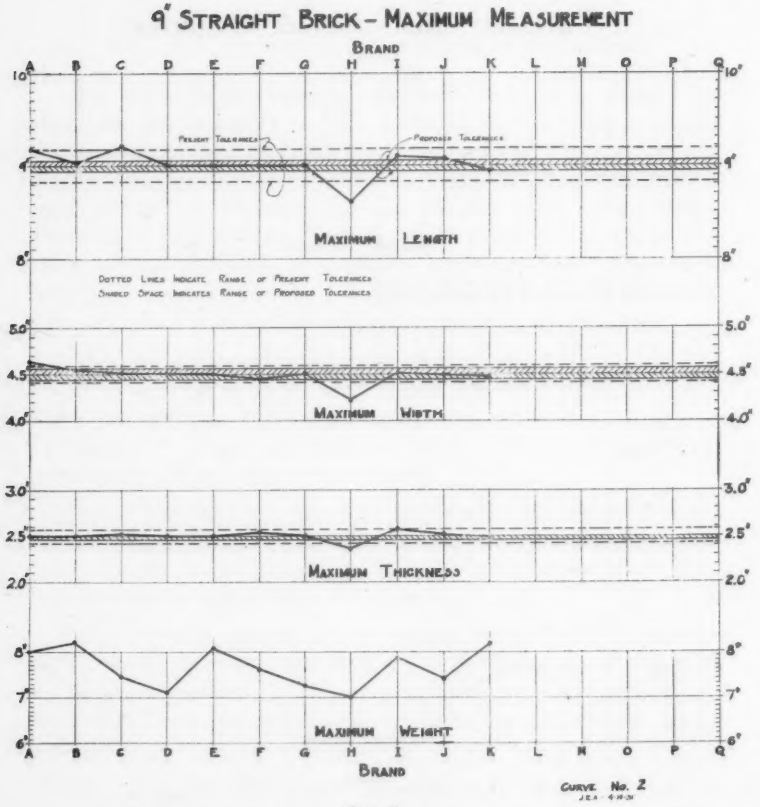
9" STRAIGHT BRICK – MAXIMUM MEASUREMENT
BRAND
A B C D E F G H I J K L M O P Q
PRESENT TOLERANCES
PROPOSED TOLERANCES
MAXIMUM LENGTH
DOTTED LINES INDICATE RANGE OF PRESENT TOLERANCES
SHADED SPACE INDICATES RANGE OF PROPOSED TOLERANCES
MAXIMUM WIDTH
MAXIMUM THICKNESS
MAXIMUM WEIGHT
BRAND
CURVE No. 2

FIG. 2.

25. We have prepared the curves of Figs. 1, 2 and 3, which indicate the average, maximum and minimum variations, respectively, in measurement and weight of sixteen different brands of 9-inch straights, representing 42 carloads of brick. These curves portray the variations in size and weight, also the relation of these variations to the present tolerances adhered to by firebrick producers; and, in addition, we have indicated by shaded areas the closer tolerances that are being advocated for the benefit of the consumer.

26. These curves tell their own story, but it might be well

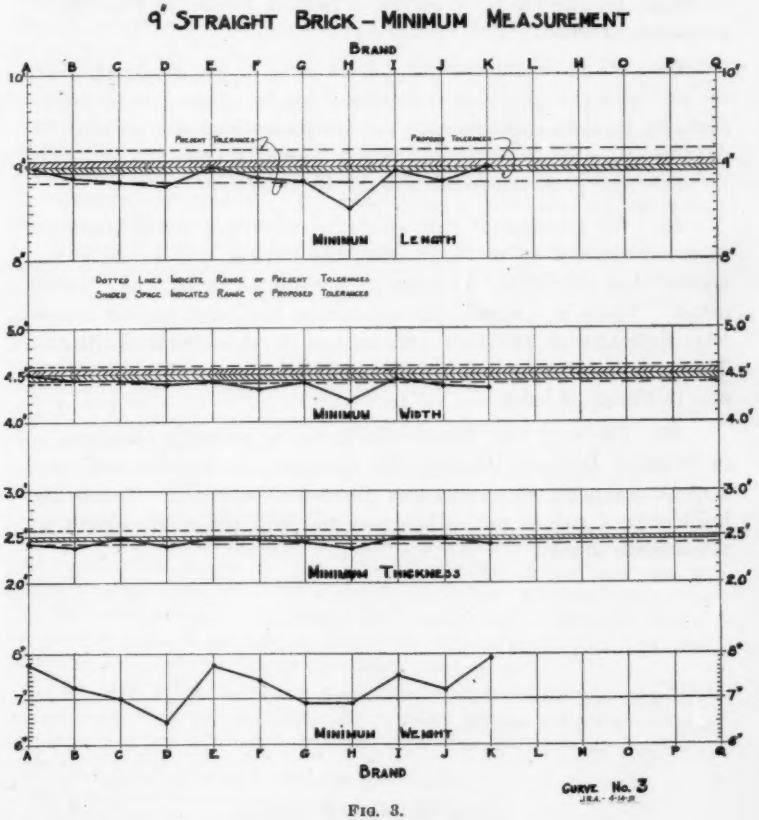

FIG. 3.

to point out that the maximum and minimum measurements and weights of these 42 carloads were as follows:

	Maximum	Minimum
Length, inches	9.21	8.55
Width, inches	4.64	4.19
Thickness, inches	2.75	2.37
Weight, lbs.	8.2	6.5

27. We have had complaints of brick size variations not only from individual foundries but from one of the large associations that represents a group of foundries. We wish to point out that this question of closer tolerances on firebrick shapes is not an easy one for the refractory producers to meet. They have many problems, peculiar to their industry, to solve before we can expect permanent relief.

28. We have had assurance from some of the producers that the tolerance specifications as proposed can be adhered to by modifications in their processes at no particular increase in cost of production.

Recommends Use of Brick Meter

29. We recommend that all foundrymen pay more attention to the tolerances on the brick they are buying, and strongly advocate that foundries familiarize themselves with the "brick meter," which is a measuring instrument perfected by the American Refractories Institute and in use at the Mellon Institute. This instrument measures the over and under size on length, width and thickness of brick.

30. The only way that firebrick can be properly measured is to measure between parallel flat surfaces which will take into account warpage, roughness and dimension variation. Measuring brick with a rule is not satisfactory nor will the measurement so taken mean much.

(*Continued on next page*)

DISCUSSION

CHAIRMAN F. M. ROBBINS:[1] This is not only a paper but a committee report as well. Remarks on this report as representing the Malleable Division of the A. F. A. are earnestly solicited at this time as a matter of record for the committee as well as a comment on the paper.

L. C. WILSON:[2] As a committee report, do I understand that we are making a recommendation for adoption of the new standard for the A. F. A.?

J. R. ALLAN:[3] This is more or less the work of the A. F. A. committee on refractories working in conjunction with the joint committee, and we are advising the A. F. A. membership of what the committee is trying to accomplish. At this meeting it should not be acted upon as a committee proposition. We simply would like to have comments on what we are trying to accomplish. Now is the only time we can reach the foundrymen in general to bring out favorable or unfavorable discussion.

L. C. WILSON: I happen to know that Mr. Allan has done a tremendous amount of investigation and constructive work on this subject. My reason for the question relative to adoption was because I wonder if the specifications as proposed are such that the refractories companies as a whole can meet them without it costing the foundries extra money for proper selection of brick to come within these specifications, and whether or not they are reasonable. I am trying to look at this now from the point of view of the manufacturer.

I agree heartily with Mr. Allan that, if we could get brick to come within a thousandth of an inch, it would help us considerably in building our furnaces. However, like the castings industry, there are certain variations in fireclays that must and do exist, and I wonder whether we are asking the firebrick manufacturers to do something that is a hardship on them, if not impossible.

J. R. ALLEN: It is not intended that the tentative tolerances be put up to the American Refractories Institute at this time for final adoption. If they were, probably a number of refractory producers would have to go out of business. Their equipment is not such that they could meet these tolerances. We think we still have a year or two of educational work ahead to get them sold on the idea.

However, it is gratifying that quite a few producers have indicated that these tolerances can be met. One or two, in fact, say they can do it now and are doing it in a few specific foundries. All foundrymen are justified in demanding a brick within the present A. R. I. tolerances, which are plus or minus 2 per cent on dimensions of 4 inches or over, and plus or minus 3 per cent on dimensions under 4 inches.

CHAIRMAN F. M. ROBBINS: I wish to speak in connection with the shipment of brick for malleable air furnaces by the refractory manufacturers. In our advisory committee work this has come up from re-

[1] Vice-President, Ross-Meehan Foundries, Chattanooga, Tenn.
[2] Plant Manager, Reading Steel Casting Co., Reading, Pa.
[3] Industrial Engineer, International Harvester Co., Chicago.

ports of various users of firebrick, our attention being called to the fact that the refractory manufacturer, in shipping to the malleable user, takes advantage of the minimum requirements.

In most types of furnaces it is understood that an over-size brick causes more difficulty than an under-size brick. In connection with the air furnace, we are concerned mostly with the number of square feet of area, and the larger the brick, the smaller the number of joints, and the smaller the amount of bonding material required.

Reports have been offered indicating that where the manufacturer takes advantage of his tolerances as given by the refractories standard and ships on the minimum size, as apparently is quite customary, refractory costs of the melter have increased as much as 15 per cent. If this is so, attention is earnestly directed to the establishment of standards such as will give at least an average-size brick and not all under-size brick.

N. M. WATERBURY:[4] Would Mr. Allan consider it appropriate at this time to give a few more details about the proper way of measuring brick? I am not familiar with this brick meter.

J. R. ALLAN: I believe Mr. Phelps can give us all that information. He was instrumental in developing the brick meter whose use he advocates—either that or some similar measuring device.

S. M. PHELPS:[5] The problem of measuring refractories for size was brought before the attention of the American Refractories Institute some years ago. There has always been more or less controversy as to how brick should be measured, as well as discrepancies between the measurements made by the producer and the consumer. This condition has become more serious in recent times in view of specifications embodying closer size tolerances. It is for this reason that there has been developed a device for measuring 9-inch brick which is called the "brick meter."

This apparatus overcomes the personal errors accompanying the measurement by means of rules or even gages. The principle employed by the brick meter is to make the measurement between plane and parallel plates. The three dimensions of a 9-inch brick can be rapidly measured to the closest one thirty-second of an inch, and sixty-fourths can be easily estimated. Its scale is graduated so as to show instantly the plus or minus variation from standard dimension.

A considerable number of brick meters are in use in manufacturers' plants, and we are glad to learn that the malleable industry also is interested in its use. So far as we can learn, the only objection to it is its weight (about 50 lbs.), although, except for this, the instrument is entirely portable.

With regard to the volume of brick supplied to the malleable industry, there is brought to our attention the report made by Mr. Allan, in which he found that producers were supplying brick which were considerably under-size. This was of concern to the Institute, and, accordingly, the Research Advisory Committee obtained measurements of side-wall and

[4] Metallurgist, Link Belt Co., Ewart Works, Indianapolis.

[5] Director of Research and Tests, American Refractories Institute Fellowship, Mellon Institute, Pittsburgh.

bung brick which were in the stock sheds of producers who represented over 90 per cent of the producers supplying this class of refractories.

This study showed that the average volume of all bung brick was 100.6 per cent of the volume of the perfect bung brick. The side-wall brick averaged 98.3 per cent. These averages, of course, represent oversize and under-size brick; nevertheless, the volume of the smallest size of bung brick was 95.5 per cent, while that of the side-wall brick was 96.2 per cent.

Upon obtaining these measurements, there was brought home to some manufacturers the necessity of paying closer attention to their mold size. After all, it is up to the individual consumer to see that he obtains brick which fall within reasonable size tolerances.

With regard to Mr. Allan's paper, it is my belief that it will be a matter of some years before it would be at all practicable to adopt the requirements which he has suggested. At the present time, only 34 per cent of the side-wall brick would meet this tolerance. Obviously, the manufacturer would have to sort all of his brick by measuring, and reject (or dispose of in other ways) 66 per cent of the side-wall brick. In the case of bung brick, only 10 per cent would pass the tolerance, and even though it were not necessary to discard such high percentages of brick in order to meet the specifications, increased cost involved by handling and sorting would, we believe, offset any advantage obtained in service from such brick.

I would suggest that the problem of joints might be overcome by using refractory units of larger size rather than by placing so much stress on the thickness of joints. It might be well, also, to consider seriously the matter of the type of cement or mortar used. This would seem to be a more economical and practicable way of solving the problem.

In the case of bung brick, there should be kept in mind the objections to making too tight or too small a joint. Such a joint would lead to the structural spalling and pinching of the heated ends of the brick, and this, in my mind, is far more serious as a cause of failure in bungs than is thermal spalling, which has received so much attention.

J. R. ALLAN: Mr. Phelps and I usually take issue on the measurement of brick. He likes to go by volume and I like to go by lineal measurement.

It is true, as he has said, that the producers have the problem ahead of them. However, there is a demand from public service companies, in building large and expensive boiler units, for very close tolerances. In fact, some of them resort to grinding the brick. It was mentioned in the symposium at the recent Cleveland meeting of the American Ceramic Society that that one producer admitted his grinding costs were $3 per thousand. I presume that the job he referred to was some large boiler installation.

Some of the producers have shown a very keen interest in working on these tolerances, and we are getting results. Many of them are shipping brick today that are a great deal more creditable than those they shipped two years ago. If we can just keep up the good work, help them

and keep after them for these tolerances, we are going to get them in line.

R. W. PARSONS:[6] In regard to the 13½-inch bung brick, we understood there were two standards, a 13 and a 13½, and were so advised by the manufacturers. It was stated rather denitely that 13½ was to be preferred, and there was something said about the disadvantages of the 13-inch series.

It makes very little difference to us whether it is 13 or 13½ inches. Could we have this point emphasized somewhat?

J. R. ALLAN: The 13-inch series was used for quite a while prior to the adoption of the Bureau of Standards recommended practice, R-78. The reason why we took the 13-inch bung series out was because it was not a multiple of 4½ inches, and many foundries use up half bats from side walls in bung construction. They use a 9-inch brick and a 4½-inch bat.

This cannot be done with a 13-inch unit, and that in itself militates against continuing the use of the 13-inch length bungs. Thirteen and one-half is a multiple of 4½ inches, as is 9.

A. VAN LANTSCHOOT:[7] It was stated here that the matter of area is of great importance. If that is true, then by all means the 9-inch brick should be reinstated as standard by the Division of Simplied Practice.

The 13-inch brick, as I see it, offers no great outstanding advantage over the 9-inch brick, but the fact remains that from the standpoint of area the 9-inch brick costs much less. As a matter of fact, the 9-inch brick costs 10 per cent less than the 13½-inch standard on the basis of area. I think that is worthy of some consideration.

J. R. ALLAN: I understand that an opportunity will be given shortly to vote on this proposition. The Bureau of Standards, Division of Simplified Practice, is circulating another questionnaire to the malleable consumers and producers, getting their reactions on any shapes they feel ought to be added to the present list. There is a demand for the 9-inch bung brick, and possibly we will have to reinstate it.

W. R. BEAN:[8] We made very careful studies of service of 9-inch and 13½-inch bung brick. What Mr. Van Lantschoot says regarding price is true, but we were very thoroughly convinced that the 13½-inch brick for bungs was a vastly better brick than the 9-inch.

In the first place, there are one-third less bungs on the furnace. Therefore, one-third of the cost of the bung frames can be deducted. Only two-thirds the number of joints have to be sealed after charging, and the greater thickness of the 13½-inch brick makes a smaller number of brick joints in the bung.

Thus, my own observation is that the 13½-inch bung brick is better, and a good deal better, than the 9-inch; that the 13½ should supersede the 13 very definitely, because many use bung assemblies which are mul-

[6] Metallurgist, Ohio Brass Co., Mansfield, Ohio.
[7] Superintendent, Iowa Malleable Iron Co., Fairfield, Iowa.
[8] President, Grindle Fuel Equipment Co., Harvey, Ill.

tiples of 4½, and it is possible to use a 9-inch with two 13's and get a staggered construction, which is a much better construction than three straight rows of brick in the same assembly. I believe that these factors make for economy and efficiency for the user of the bung shapes.

I believe that in side walls there is a place for larger shapes than the 9-inch. In my earlier experience in the malleable industry we used what was called the large 9-inch brick, which is one and one-half times the 9-inch for side walls exclusively. We found that a man could lay just as many of those in a given length of time as he could the 9-inch brick. The vertical joints, which are the joints to be given special consideration from the standpoint of wall run-outs, were reduced by one-third, and I believe that experiments have been made with larger brick than the large 9-inch, although I have made no definite records as to the success achieved.

My feeling has been that anything much thicker would not get the uniform burn and therefore would not be as serviceable in a side wall. In other words, a tile would not be as serviceable in a wall as the smaller shapes.

The final analysis, of course, is the consensus of opinion and of tests, and in connection with the gaging of brick there is just one thought I would like to leave with the committee. While it would not be practical, in the receipt of brick, to gage every brick, a certain relatively small percentage which might be passed over this 50-pound gage might be attempted. The instrument could not be carried around so as to gage every brick, but a certain definite percentage could be gaged, which would give a fairly good idea as to how a car of brick is running as to size discrepancy.

The users of the brick will have to cooperate with the committee and work out the problem in this way. It is not a two-sided problem to be handled just by the committee of the A. F. A. and the manufacturers. The users must do some testing and contribute their results in order to get the right answer in the final analysis.

A. VAN LANTSCHOOT: I wish to correct one of the impressions which Mr. Bean has just left. When we used the 9-inch brick for bung, naturally we laid them up two brick end to end. The bung, therefore, was 18 inches wide. This means that we only had three bungs, where otherwise there would be four. It is an easy matter to lay up a bung along these lines. We make joints only every third course.

Another advantage of the 9-inch brick is that this brick as a rule comes true to size. Therefore, we have smaller joints.

I have kept track of the life of bungs over a good many years. I have very good data on hundreds of bungs, and I believe the 18-inch bung made of 9-inch series will not have to "take off its hat" to the 13-inch bungs in any way, shape or form.

J. H. LANSING:[9] I believe that the difference between Mr. Bean's experience and that of Mr. Van Lantschoot, in the matter of the 9-inch

[9] Danville Malleable Iron Division, Allith-Prouty Co., Danville, Ill.

bung brick, really can be accounted for by the fact that Mr. Bean, as I understand it, is considering 9-inch brick as a single 9-inch width bung, whereas Mr. Van Lantschoot is considering an 18-inch bung.

Some people even build up and use a 27-inch bung, and the conditions there are entirely different. In the 18-inch or 27-inch bung this is built up as a solid bung without the joints—the open joints, which have to be sealed after the bung has been put on the furnace—which are present in the case of using individual 9-inch bungs.

W. R. BEAN: My comments cover both the single and the multiple. I had in mind the two conditions.

J. R. ALLAN: I might amplify Mr. Bean's remarks about testing carloads of brick. The carloads referred to in this report had anywhere from ten to fifty bricks per car measured.

Referring to the other remarks about 9-inch bung brick, or the service one foundry gets out of certain construction as compared with another, it is nearly impossible to find two foundries that get the same results and have the same conditions. There are many variables involved. Many times those in one foundry will not be adopted by another foundry.

W. H. DOERFNER:[10] We do not use many side-wall bricks, but we do use a lot of cupola block. Some time ago we noticed that the blocks were becoming smaller, and we were receiving quotations as much as two cents apiece under our usual price. We became suspicious and started to weigh the brick; now we weigh every carload of brick by the thousand. We check a thousand cupola block, and I believe we now are getting what we are paying for. The fact is, we have made several of our manufacturers return us money on that basis.

CHAIRMAN F. M. ROBBINS: I might say, in this connection, that there was a suggestion made to the advisory board that brick be bought by the ton.

W. H. DOERFNER: We also buy ours that way now. We buy them, of course, by the piece, which is translated back on to a ton basis, so that we now are getting what we are paying for.

L. J. KELLY:[11] I would like to ask Mr. Allan if his investigation covered silica brick. We are using silica brick in our open-hearth furnace, and I might say that we like to get a more refractory brick.

J. R. ALLAN: Any investigation in silica brick is being handled by our sub-committee on electric furnaces. We have no open-hearth committee as yet, although we hope to get one organized.

The committee has not felt it practical to go into the refractory qualities of brick. We felt that was largely a matter for the producer to meet, and we do not want to dictate refractory qualities on firebrick. That is treading on dangerous ground.

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[10] Works Manager, Saginaw Malleable Iron Div., Saginaw, Mich.
[11] Superintendent, Fort Pitt Malleable Iron Co., Pittsburgh.

R. J. TEETOR:[12] To buy brick on a tonnage basis would simplify the matter very materially for the refractory manufacturers, of course, because their interest is not so great in confining their manufacture within the limits we desire.

As a suggestion to this committee, however—which would put pressure on the refractory manufacturer to come within closer limits—we believe that a lower limit should be given, this to be the exact dimension and nothing under that accepted, and leaving out all maximum limits. This would automatically force the refractory manufacturer to hold his weight and over-size dimensions to a very minimum. Unless he should keep his brick down to the exact size, he would be penalized by giving overweight for which he could make no charge.

If the manufacturer is given a limit within which he can easily work, he will, as has already been suggested, naturally go as close to the upper limit as he can if he is selling brick by the ton, and as close to the lower limit as possible if he is selling by the piece.

If a lower limit only is established, this puts it right up to the manufacturer. The malleable founders are used to that sort of a specification, and possibly the refractory manufacturers also could live down to such a limit.

E. E. GRIEST:[13] In the tolerances for face thickness, a dimension of plus 0 and minus 3/64 inch are given. Would there be any objection to having tolerances for all of the dimensions, plus 0 and minus ⅛ inch for the length and width dimensions?

J. R. ALLAN: No, there would be no particular disadvantage in that. The only thing we are trying to adhere to is the nominal 9-inch size—the $4\frac{1}{2} \times 2\frac{1}{2} \times 9$, so that they would average out the nominal size.

E. E. GRIEST: There seems to be a great deal of comment from some of the foundry people as to the small brick that they are getting. If a minimum dimension were specified, if the tolerances always were over, then there would be no cause for complaint.

It seems to me that, while Mr. Teetor's suggestion is all right for most conditions, yet there might be a condition where one would want to limit the maximum dimensions, particularly in an open-hearth furnace, as Mr. Kelly mentioned. Has the committee given any consideration to the adoption of a one-way limit?

J. R. ALLAN: That was given thought, but in tolerances on various commodities it usually is a plus or minus proposition, except that when it comes to the finished steel shapes—cold-rolled and stock of that material—it may run plus zero, minus a certain number of thousandths. The general practice in applying tolerances is plus or minus on the nominal size.

We did limit it on the thickness because the consensus of opinion was that we had better not have the brick over $2\frac{1}{2}$ inches, and get it as close to $2\frac{1}{2}$ as we could.

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[12] General Manager, Cadillac Malleable Iron Co., Cadillac, Mich.

[13] General Superintendent, Chicago Railway Equipment Co., Chicago.

I might repeat these tolerances again. We have been working to the tentative tolerances of plus or minus 1/16 inch on length dimensions. That may mean 9-inch brick, 13½-inch brick or whatever standard shape it is. Then a plus or minus 1/16 inch is specified on any width dimensions of a 9-inch straight, or a 13½-inch bung or tap-out block, or whatever the shape may be. On face thickness dimensions, plus 0 and minus 3/64 inch are specified.

CHAIRMAN F. M. ROBBINS: The chairman of your refractories committee would appreciate some expression of opinion, in this connection, by a vote. This is merely as a method of guidance in the work of the report, as the report is not yet in shape for formal action.

W. R. BEAN: I move that we signify approval of the committee's recommendation, namely, that we are in favor of the tolerances given in Mr. Allan's report and which are plus or minus 1/16 inch on length, plus or minus 1/16 inch on width, and plus 0 and minus 3/64 inch on thickness.

(*The motion was seconded and approved by a divided vote.*)

Electric Process Iron for Cylinder and Cylinder-Head Castings

By H. E. Bromer,* Racine, Wis.

Abstract

In order to produce a consistently better grade of iron than was possible by cupola melting alone, an electric furnace was installed. Experimental work was carried on while using both types of melting furnaces. Later, during high-production periods, the duplex process was used, melting in the cupola and refining and increasing temperatures in the electric furnace. During periods of low demand, melting from cold stock in the electric furnace proved most economical. Details of the various practices are given. Close control of chemical analyses and physical properties were obtained by the electric furnace process, especially as applied to strengths and hardness. Strengths produced ranged from 40,000 lbs. per sq. in. tensile strength for plain irons to 60,000 lbs. for special alloy irons.

1. In January, 1928, the Standard Foundry Co., Racine, Wis., installed a 3-ton-per-hour electric furnace with the express purpose of producing a consistently better grade of iron at a cost which would compare favorably with cupola figures. At this time the plant layout consisted of one conveyor unit capable of handling approximately fifty tons of iron per 10-hour day, together with side floors which had a combined capacity of approximately forty tons per day.

Batch Melting Used at Start

2. This arrangement of the plant permitted the operation of the electric furnace on a batch operation making from 20 to

* Metallurgist, Standard Foundry Co.

Note: This paper was presented before one of the gray iron sessions at the 1931 convention of the American Foundrymen's Association.

30 tons per 10-hour day to take care of part of the side-floor work, while the cupola produced iron for the balance of the side floors and for the conveyor unit where a continuous supply of iron was essential. Such an arrangement of the operating schedules of the two melting units was ideal, as it permitted a long period of experimental and development work on the electric furnace, and at the same time afforded ample opportunity for studying the operation, characteristics and economies as well as the relative quality of the two irons produced.

3. This general procedure was followed for a period of a little more than a year and a half, during which time much valuable information was obtained as to the analysis and characteristics of electric-furnace iron most suitable for cylinder and cylinder-head castings. Also, it was proved conclusively that it was highly desirable to place the entire production of the plant on electric-furnace iron.

4. Furthermore, the addition of a second conveyor unit made it imperative to have a continuous supply of iron throughout the day, so that it was decided to try duplexing on a continuous basis. This was something which had heretofore not been tried on gray iron, although much valuable work had been done by Kerpely and the late George Elliot on duplexing on a batch basis, filling the furnace with molten cupola iron and then proceeding to run the heat the same as would be done after melt-down on a cold-melting batch operation.

DUPLEXING PROCESS

5. The electric furnace and cupola were already installed side by side, so that all that was necessary was to extend a refractory-lined spout from the side of the cupola connecting with a second movable refractory-lined spout, which in turn emptied into the electric furnace at the rear door. With these preparations completed, duplexing operations accordingly were started during the first week of September, 1929, and since that time the entire output of the plant has been of electric-process iron.

Equipment

6. The equipment consists of a standard Whiting No. 7 cupola connected to a 3-ton-per-hour "Lectromelt" furnace by

means of the movable refractory-lined spout, already described. This layout is shown in Fig. 1.

Preliminary Procedure

7. The cupola is lined to 48 inches and is charged in the usual manner, one-ton charges being used on a 40 inch high (above the tuyeres) coke bed with from 135 to 150 lbs. of coke between charges, depending on the nature of the charge itself

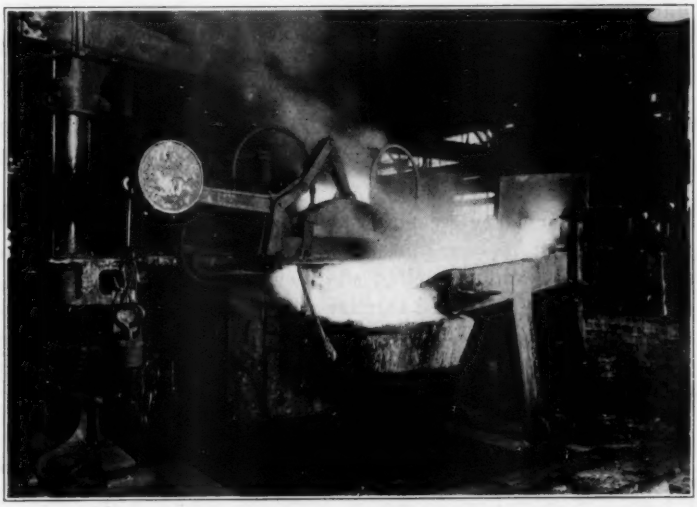

FIG. 1—ELECTRIC FURNACE INSTALLATION, SHOWING ARRANGEMENT OF CUPOLA SPOUT FOR CHARGING MELTED IRON IN ELECTRIC FURNACE FOR DUPLEXING.

and the characteristics of the coke. After the cupola has stood for a period of from one-half to one hour fully charged, blast is turned on and in from 8 to 10 minutes the first iron runs over the spout into the electric furnace. This remains in the furnace without power on until the first full tap is received, when power is put on and the superheating and adjusting of analysis is started.

8. A bath of from 15,000 to 18,000 lbs. is built up of the periodic taps from the cupola, after which the cupola is shut down and the necessary steel, ferrosilicon and ferromanganese additions

are made. These are controlled by tests taken from each cupola tap and by tests taken from the electric furnace bath.

9. The cupola is operated so that the carbon is higher and the silicon and manganese lower than that desired in the finished product, which permits of easy adjustment of these elements to the proper points.

Melting and Tapping

10. Approximately one and one-half hours after blast is originally put on, tapping operations from the electric furnace are started and can be made at whatever rate required by the two conveyor units. Usually, taps of 1200 lbs. are taken out every five to six minutes, or at the rate of approximately 6 tons per hour, although the capacity of the equipment permits operations up to 12 tons per hour if necessary. For this production the cupola would, of course, have to be lined larger so that its full capacity could be utilized.

11. After every second 1200-lb. tap, the bath again is built up by tapping molten iron from the cupola together with the necessary steel and ferroalloy additions. This alternate tapping and charging is continued throughout the day until such time as the total tonnage has been melted in the cupola and the bottom dropped, from which point the process merely involves emptying the furnace by tapping as previously.

12. After the furnace has been emptied and fully drained, the bottom is patched wherever necessary by using a few shovels of sand, as an acid bottom is used for this process. Only this brief description of the duplex process is given here as this process, together with operating data, has been fully covered in a previous article.[1]

CONTINUOUS COLD-MELTING PROCESS

13. The flexibility of the electric furnace installation under various tonnage conditions is well illustrated by the change from duplexing to continuous cold melting. For tonnages over 25 tons per day, the duplexing process supplying iron at the rate of from 4 to 6 or more tons per hour fits in very well with the continuous

[1] Bromer, H. E., "Duplexing with Cupola Makes High-Grade Iron Castings." *Iron Age*, vol. 125, May 8, 1930, pp. 1372-1376.

pouring schedule demanded by conveyor operations, and the operating costs are approximately the same as the costs of running the cupola alone.

14. However, during periods of business depression when low tonnages are a necessity, duplexing under 25 tons per day becomes expensive and impractical from the standpoint of a continuous operation of one of the conveyor units. Continuous cold melting then becomes the cheaper and more practical method, as a continuous supply of iron may be had throughout the day and advantage can be taken of comparatively low-cost melting materials such as cast-iron borings.

15. No change was necessary in the electric furnace in order to start continuous cold melting, except for the removal of the large spout at the charging door and the substitution of the regular spout. As these hook on the furnace, there is practically no expense involved in changing from one process to the other.

Typical Operation

16. A typical day's operation of the furnace using the continuous cold-melting process may be of interest at this point.

17. The first charge consists of 7700 lbs. of cast-iron borings, 3500 lbs. of cast scrap (our own returns together with purchased motor-block scrap) and 2800 lbs. of steel, a total of 7 tons. The helper and two laborers charge 5 tons of this in the furnace and have power on by 4:30 A. M., and about 6:15 A. M. the balance of 2 tons is put in and melting continued.

18. At 7 A. M. the melter comes in and, after making his ferrosilicon, ferromanganese and, if necessary, his petroleum coke additions, takes one or more tests and is ready to make the first tap about 7:30 A. M., with the bath, of course, up to pouring temperature of approximately 2950 degs. Fahr. After this tap, 1250 lbs.—made up of the same relative proportions of borings, scrap and steel—are charged together with the necessary ferroalloys, and in from 15 to 18 minutes the next tap is ready.

19. This alternate tapping and charging is continued throughout the day until sufficient tonnage has been charged (usually about 3:45 P. M. for a 25-ton day), from which point on the furnace is emptied as fast as molds are available.

20. After the furnace has been fully drained, the bottom is

patched with sand, a mixture consisting of four shovelfuls of silica sand to one shovelful of red sand having been found to work best.

21. Furnace tests are taken, of course, throughout the day's run to serve as a guide to the melter, and chemical analyses for silicon and carbon are taken usually at least eight times throughout the day, or an average of about once an hour. Manganese, sulphur and phosphorus also are checked each day but not as often as carbon and silicon, the two principal elements in the control of cast iron.

Power, Electrodè and Refractory Consumption

22. Power consumption for the continuous cold-melting process is averaging between 540 and 550 kilowatt-hours per ton, while the electrode consumption is slightly over 12 lbs. of graphite electrodes per ton. Both of these items might be improved somewhat if the furnace were operated to its full capacity, as the power demand has been held down to 1000 kilovolt-amperes (full capacity would be 2000 kilovolt-amperes) in order to earn as low a power rate as possible, by having a high load factor on a comparatively low demand.

23. For a total tonnage output of 500 tons per month with the low demand, and including the plant power and demand, the average cost per kilowatt-hour is approximately 1.13c.

24. Refractory life is not as good as for the duplexing operation, but for the roof removed Feb. 14, 1931, a total of 800 tons were melted, while 1204 tons were obtained on the side walls removed at the same time. Average figures, however, show approximately 600 tons for a roof and about 1000 tons for a side-wall lining. The bottom is patched daily with sand and about once a week with ganister, depending on its condition.

CONTROL OF CARBON AND SILICON

25. The advantages of the electric process, either continuous duplexing or cold melting, are many. Chief among them is the control of carbon and silicon, the two most important elements in gray iron. The curves of Figs. 2 and 3 are given as examples of what has actually been accomplished in the operation of the electric furnace.

26. The figures plotted in these curves represent daily aver-

ages, as it was impossible to show on these curves the variations throughout each day's run; and, if only one day's run were shown on the curve, it would naturally be open to the suspicion that the best day was selected. The variations throughout each day, however, average well under twenty points for both carbon and silicon, except, of course, where low or high carbon or low or high silicon were made purposely to meet special requirements.

27. The flexibility of the process in this respect is unlimited, as low-carbon high-silicon iron or any combination desired may

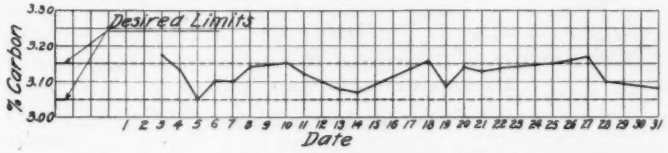

Fig. 2—Carbon Control. One Month's Operation of the Electric Furnace.

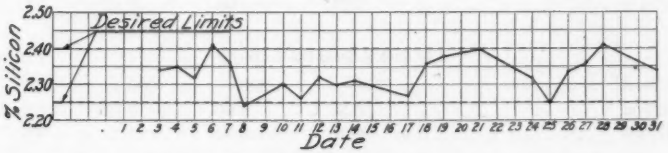

Fig. 3—Silicon Control. One Month's Operation of the Electric Furnace.

be made first thing in the morning for special jobs and then, after adjusting the carbon and silicon to the proper points, the regular production may be proceeded with as usual.

Uniformity in Analysis and Hardness of Cylinder Blocks

28. Another example of the uniformity of analysis obtained from the electric furnace is had from a study made of 100 motor blocks made for the manufacturer of one of America's highest priced cars. The production of these blocks extended over a period of eight days and, as only ten flasks were available, it was necessary after the first three days, in order to meet the production schedule, to make ten molds in the morning, pour them off, and then make ten more in the afternoon. Thus, the iron in these

blocks represented various parts of the day's run as well as a period of eight days' operation of the furnace.

29. The Brinell hardness, as well as carbon and silicon determinations, were made on each of the 100 castings and each casting was numbered from 1 to 100 so that it could be followed through the machine shop and through its life in the motor car. Twenty of the 100 castings were made (spread over two days' run) with a higher carbon range and a slightly lower silicon range to give a lower average Brinell hardness in the bore, in order to determine, if possible, the effect of this higher carbon in machinability and wear resistance. The summary of data obtained on each of the two groups making up the 100 cylinders are given in Table 1.

Table 1

EFFECT OF CARBON CONTENT ON PROPERTIES WHICH DETERMINE MACHINABILITY AND WEAR RESISTANCE

	High	Low	Avg.	Points variation
High Carbon Group (20 Castings)				
Brinell	207	196	198	11
Carbon	3.34	3.21	3.29	13
Silicon	2.25	2.08	2.15	17
Low Carbon Group (80 Castings)				
Brinell	217	202	209.5	15
Carbon	3.20	3.00	3.08	20
Silicon	2.30	2.15	2.21	15

UNIFORMITY OF PHYSICAL PROPERTIES

30. Next in importance to the control of the chemical analysis is the uniformity of the physical properties. This naturally follows uniform chemical analysis and control of melting and superheating conditions, so that it is not surprising to find the transverse strength, deflection, Brinell hardness and structure remarkably uniform from day to day.

31. The curves of Fig. 4, taken from actual customers' reports, show the high and low Brinell for the same month's operation of the cupola and the electric furnace. The points where the

curves cross each other simply mean that all blocks made on that date Brinelled exactly the same.

32. The importance of Brinell or some other method of measuring the hardness of motor blocks cannot be overestimated, and it is important not only from the standpoint of uniformity in Brinell from casting to casting but also within each casting itself. Superheating in the electric furnace is the real answer to this

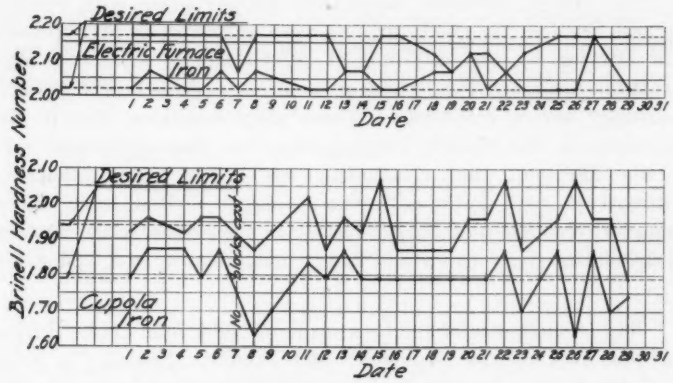

FIG. 4—ACTUAL CUSTOMERS' REPORT OF BRINELL HARDNESS ON CYLINDER BORE COVERING ONE MONTH'S OPERATION. UPPER TWO CURVES SHOW HIGH AND LOW BRINELL HARDNESS IN CYLINDER BORES OF ELECTRIC-FURNACE IRON. LOWER TWO CURVES SHOW HIGH AND LOW BRINELL HARDNESS IN CYLINDER BORES FROM CUPOLA IRON. THE DIFFERENT DESIRED LIMITS OF HARDNESS OF THE ELECTRIC-FURNACE IRON AND CUPOLA IRON WERE THOSE SPECIFIED BY THE CUSTOMER. IT IS INTERESTING TO NOTE THAT THE ELECTRIC-FURNACE IRON, WITH ITS HIGHER LIMITS OF HARDNESS, MACHINED WITH MUCH LESS DIFFICULTY THAN THE CUPOLA IRON WITH ITS LOWER HARDNESS LIMITS.

last condition, as a uniform structure is produced throughout the casting, with a fine, even distribution of graphite flakes in both the thick and thin sections.

33. Microscopic examination, as well as the Brinell test, prove this statement conclusively, as cylinder blocks made of electric-furnace iron when Brinelled on the bore, on the bearings and on the cope flange, show an average variation of approximately fifteen points, while blocks produced from cupola iron showed a variation when Brinelled on the same places of from forty to sixty points.

34. The electric furnace brings this result through superheat and without the use of expensive alloys, thus giving the electric process an advantage over the cupola, where it is unquestionably true that the addition of certain alloys produces a more uniform structure but at a rather large increase in cost.

ALLOYS IN ELECTRIC FURNACE IRON

35. Alloys, however, have their proper place with electric furnace iron, as the good, uniform base mixture can be improved still further by the addition of alloys where especially high strengths are needed or where a motor is expected to withstand unusually severe conditions. These alloy additions, due to the superheat of the electric furnace iron, are thoroughly and uniformly dissolved, thus eliminating one of the main difficulties encountered with ladle additions to cupola-melted iron. Four grades of iron are in daily production at the present time, namely, nickel-chrome iron (high and low), molybdenum iron and plain iron.

36. A summary of the tests made on these four grades during the past two months (December and January, 1930-31) is given in Table 2. The bars broken (except where noted) were the old standard A. F. A. 1¼ in. round bars broken on 12 in. centers. These were made in the standard way in every respect, except that the molds were made in green sand instead of in dry sand. This should give, if anything, slightly lower results than the standard method of dry-sand molds.

37. It is worthy of note that, of the 88 bars of plain iron tested, all but 17 were within the narrow limits of 4400 to 5000 lbs. Of these 17 bars, seven were slightly below 4400 lbs., while 10 were above the 5000-lb. mark, a record for consistently high strength which is practically impossible to achieve in the cupola in day-to-day production, even though expensive allows are used.

38. As a check on the summary of results given in Table 2, it is interesting to consider the results reported by one motor builder who receives and tests in their own laboratory standard 1¼-in arbitration bars. This report for December, 1930, covering the various types of iron made for them in our electric furnace, is as follows:

	No. of Bars Tested	Strength, in Lbs. High	Low	Av.
Plain iron	16	5120	4260*	4747
Nickel-Chrome iron (Low)	7	4860	4540	4690
Molybdenum iron	10	5520	5100	5253

39. Tensile strength tests have not been run regularly, but the average shown for plain iron is approximately 40,000 lbs. per sq. in. on test specimens machined from 1¼-in. round bars. The average for the low nickel-chrome iron is about the same, while the iron with the high nickel-chrome content shows an average of about 45,000 lbs. per sq. in. tensile strength, with the molybdenum iron averaging approximately 50,000 lbs. per sq. in. Special alloy irons have also been made for certain jobs where the tensile

Table 2

SUMMARY OF RESULTS ON TRANSVERSE TESTS

	No. of bars tested	Average strength, in lbs.	Average Deflection, in inches
Plain iron	88	4738	0.128
Plain iron (18-in. centers)	14	2722	0.24
Nickel-chrome iron (Low)	32	4740	0.137
Nickel-chrome iron (High)	42	4738	0.13
Molybdenum iron	41	5400	0.157

strength ran over 60,000 lbs. per sq. in., with a transverse strength as high as 7000 lbs. and a deflection of 0.18 inch. These irons are interesting for special applications, but their alloy cost is rather high, making them prohibitive for ordinary work.

40. When considering the high strengths listed in this article for the electric furnace iron, both alloy and plain, it should be kept in mind that all of these irons are poured into cylinder and cylinder-head castings where the average section is from ¼ to ½ inch thick, with many of them only 3/16 inch thick. At the same time all castings have to be easily machinable, as one can readily realize from a knowledge of present-day production lines in automobile and motor-builders' shops.

41. It is true that by melting high-steel mixes in the cupola and by using special alloys, high strengths have been obtained from cupola iron, but these irons are only suitable for heavy cast-

*Only two bars were below 4500 lbs.

ings and are entirely too hard for cylinder and cylinder-head castings or similar work.

IMPACT TESTING OF INTEREST

42. Impact testing is another form of physical test that is of considerable interest, and tests thus far made have indicated that electric furnace iron has approximately twice the impact strength of cupola iron of similar analysis and made for a similar class of castings. It has also shown that, by the proper use of alloys, this already high value for electric furnace iron can be doubled.

43. An interesting report in connection with this question of impact testing is contained in a letter received from the National

Table 3

ANALYSIS OF ELECTRIC-FURNACE IRON

	Per cent
Total carbon	3.09
Silicon	2.34
Manganese	0.68
Sulphur	0.099
Phosphorus	0.159
Nickel	0.30
Chromium	0.11

Gas Engine Co., Ltd., of Ashton-under-Lyne, England. These people, in visiting our foundry, asked for a set of test bars to take back with them, and they in turn gave these bars to the British Cast Iron Research Association. Their letter to us quotes from the report of this Association in part as follows:

> "With reference to your letter of the 24th of June, the test bars tested in transverse at 12-in. centers broke at 4250 lbs., corresponding with a rupture stress of 29.3 tons per sq. in., giving a deflection of 0.13 inch. The tensile strength on the broken bar machined to 0.798 inches was 18.2 tons per sq. in. Our standard repeated impact test gave 2368 blows to fracture."

44. The analysis of the sample is as given in Table 3.

45. Two photomicrographs were enclosed with this letter, and these are reproduced in Fig. 5. Fig. 5-*A* shows an unetched

specimen at 50 diameters, while Fig. 5-*B* is the same iron etched to show the pearlitic structure at 200 diameters.

46. It is realized, of course, that this report represents only one isolated test, but it was made on a bar picked at random and which proved to be below the average in transverse and tensile strength. The impact value obtained, however, is remarkable in the light of the usual impact values as given by J. G. Pearce[2] before last year's meeting of this Association, when he said: "An

[2] Pearce, J. G., *The Correlation of Mechanical Tests for Cast Iron.* TRANSACTIONS AND BULLETIN, A. F. A., December, 1930, p. 707, par. 164.

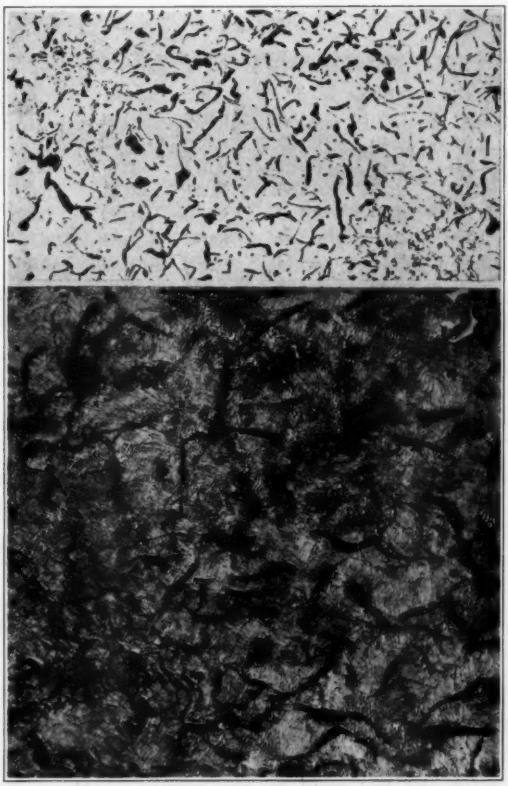

FIG. 5—ELECTRIC FURNACE IRONS. ABOVE: UNETCHED, X 50. BELOW: SAME IRON, ETCHED WITH PICRIC ACID, X 200.

ordinary cylinder iron withstands from 200 to 300 blows, while a special engineering iron may withstand from 800 to 1000."

Electric Furnace Iron for Valve Tappets

47. Another test which can be classed only as a special test, but which nevertheless reflects this higher impact value of electric furnace iron, is one that was carried out by one of America's largest automobile manufacturers. At their request we made for them some 200 valve tappets poured from six different days' heats so that the tappets would be thoroughly representative of the elec-

Table 4

ANALYSIS OF ELECTRIC-FURNACE IRON VALVE TAPPETS

Date	TC	Si	P	S	Mn	Ni	Cr
9-23	3.28	2.30	0.163	0.076	0.84	0.74	0.03
9-23	3.16	2.40	0.169	0.056	0.82	0.67	0.03
9-25	3.24	2.35	0.127	0.077	0.83	0.70	trace
9-25	3.22	2.25	0.196	0.051	0.81	0.68	trace
9-29	3.22	2.30	0.166	0.080	0.82	0.68	0.03
9-29	3.30	2.30	0.169	0.042	0.81	0.65	0.03
9-30	3.16	2.35	0.174	0.070	0.84	0.70	0.04
9-30	3.16	2.40	0.168	0.044	0.85	0.57	0.04
10-6	3.27	2.30	0.163	0.076	0.81	0.62	0.03
10-6	3.22	2.30	0.166	0.061	0.84	0.63	0.03
10-7	3.27	2.30	0.166	0.076	0.78	0.71	0.05
10-7	3.22	2.40	0.164	0.048	0.77	0.61	0.03

tric furnace iron and, if successful, could not be classed as a "lucky" ladle or heat.

48. Two molds were poured each day, using the regular analysis of iron for cylinder and cylinder-head work, and the report of the automobile company's laboratory covering the chemical analysis is illustrative of the uniform results obtained with the electric furnace. These data are given in Table 4.

49. The tappets were cast, of course, against a chill so that the entire head was chilled through, but not into the stem as this has to be bored out to within one-half inch of the head.

50. With the test used by this company, the ordinary iron tappets stood up anywhere from 3 seconds to 3 minutes, with occa-

sional ones doing much better but with nothing consistent in the performance. The steel tappets stood up under the test about an hour without breaking, and anything that ran this long was considered satisfactory. The electric furnace iron tappets were first run for an hour, and then an additional run of five hours was made without breaking any of them.

51. These various facts with reference to impact testing have been cited simply to show the possibilities of electric furnace iron. Comparisons of various impact tests are difficult and mean little, but it is hoped that a standardized impact test will soon be established so as to make more definite comparisons possible.

CONCLUSIONS

52. Much has already been accomplished in the production of high-quality electric furnace iron on a commercial basis, and the fact that this has been done during the past three years in direct competition with cupola costs means that the gray iron foundry business stands at the door of a new era. Much business that has been lost in the past to steel and malleable iron, due to the low strength and general unreliability of cupola metal, now will be regained, and engineers generally will learn that they now can write specifications and be sure of obtaining them in cast iron, as they have been accustomed to do in steel.

DISCUSSION

WRITTEN DISCUSSION

J. G. PEARCE:[1] I have read Mr. Bromer's paper with great interest and take pleasure in confirming the figures given (*see paragraphs 43-46, inclusive, and Table 3*) from the test carried out by the British Cast Iron Research Association.

With reference to the exceptionally good impact figure obtained on this iron, while the impact figures quoted in my exchange paper* to the

[1] Secretary, British Cast Iron Research Association, Birmingham, England.

* Pearce, J. G., *The Correlation of Mechanical Tests for Cast Iron*, TRANSACTIONS A. F. A. (1930), vol. 38, p. 673.

A. F. A. in 1930 are generally correct, the impact test at that time was in its infancy and a good deal of experience has since been gained. Since that date we have had impact tests on commercially made irons going up to 9000 blows under the standard conditions; that is an energy input of 0.48 foot-lbs. on a standard Stanton bar with round notch.

ORAL DISCUSSION

H. E. BROMER: Subsequent correspondence with Mr. Pearce shows that the irons with the high impact values mentioned by him (*see written discussion, above*) analyze as follows:

Total carbon, per cent	2.4 to 2.8
Silicon, per cent	1.6 to 2.2
Manganese, per cent	0.9
Sulphur and phosphorus	low

together with the usual small additions of nickel and chromium, having 1.0 to 1.5 per cent nickel and 0.25 to 0.50 per cent chromium.

G. PHILLIPS:[2] In reporting the transverse test, was the accurate measurement of the bars considered? The tendency is to have a slightly over-size bar.

H. E. BROMER: The strengths were not corrected for accurate measurement but the bars were checked, and in very few cases were they over-size.

MEMBER: In the previous paper read by Mr. Vogel* it was stated that they cast at 2950 to 3000 degs. Fahr., superheated metal. Has Mr. Bromer attempted to cast cylinders at that very high heat, or does he allow the metal to cool down after drawing it from the electric furnace?

H. E. BROMER: Our average tapping temperature, according to optical pyrometer measurements which we carried on for several months, was around 2950 degs. Fahr. By the time the metal was delivered to smaller ladles and down on the floor, it naturally would drop. I believe that considerable work was poured at around 2800 degs. Fahr.

MEMBER: Referring to Mr. Bromer's Table 4, where total carbons run over 3 per cent, it is stated that the 0.60 per cent nickel is used for a chilled tappet. What is the object of the high content of nickel in that case?

H. E. BROMER: There was no particular object. At that time we were running considerable high-nickel chrome iron, so that our iron averaged that nickel content without any ladle addition. It was simply from our returns.

J. T. MACKENZIE:[3] The papers by Mr. Vogel and Mr. Bromer have

[2] Metallurgist, Frank Foundries Corp., Moline, Ill.

* Bennett, J. C., and Vogel, J. H., *Melting of Gray Iron and Malleable Iron in the Indirect-Arc Furnace*, TRANSACTIONS AND BULLETIN, A. F. A., August, 1931, p. 235.

[3] Metallurgist, American Cast Iron Pipe Co., Birmingham, Ala.

made mention of the standard arbitration bar. I think it should be mentioned that the standard arbitration bar now is of 1.2 inch diameter broken on an 18-inch span. The bars reported in these papers are made according to the specification for the old arbitration bar.

H. E. BROMER: I might mention in this connection that it was pointed out in my paper, in paragraph 36, that the old standard bar was used. We used the old standard simply because our data had been built up on that basis. We also are casting the new bar.

MEMBER: The previous paper to Mr. Bromer's gave a refractory cost of $2.50 a ton. Mr. Bromer reports a refractory cost of 39 cents a ton. What would cause this difference?

H. E. BROMER: We are using a direct-arc type of furnace with a silica brick lining. As will be seen from the figures given in the paper, the roof that was removed on February 14 had gone over 800 tons.

MEMBER: Was this 39 cents a ton on cold melting?

H. E. BROMER: Yes, it was obtained on cold melting. On duplexing it is a different story. The roof life then, depending on the tonnage output, will go anywhere from 1500 to 3000 tons. Our cost on about 40 tons a day was down close to 10 cents a ton on refractories for duplexing.

Cupola Melting of Brass

By T. Mauland,* Chicago

Abstract

This paper describes the melting of brass in a cupola when the fuel used is of high fixed carbon content. The fuel runs 98 per cent or more in fixed carbon and is low in sulphur and ash. The cupola used is small, lined down to 22½ inches inside diameter and is operated on low blast pressure and low air volume. The lining used is a monolithic silicon-carbide cement, with a backing of firebrick and an insulating brick. Alloys melted are the 85-5-5-5 and 80-10-10 composition. For the first, the principal loss is in zinc, and for the second, lead. The castings produced consist largely of carburetors and bushings and some of these, being light, are poured at a temperature as high as 2300 degs. Fahr.

1. Since the introduction of fixed carbon fuel several years ago, the cupola melting of bronze metals has been coming to the front. The brass foundry with which the writer is connected has been melting bronze in a special cupola for the past two and one-half years. This short paper on the subject does not pretend to bring out any new ideas but is intended to set forth briefly our experience and practice with this form of melting.

Fuel

2. Fixed carbon fuel is a form of pitch coke produced by the Barrett Company, and is used in cupolas under license arrangement. The fuel runs 98 per cent and better in fixed carbon and is very low in sulphur and ash, making it an ideal fuel for nonferrous cupola operation.

*Metallurgist, Deering Works, International Harvester Co.

Note: This paper was presented before one of the nonferrous sessions at the 1931 convention of the American Foundrymen's Association.

Cupola and Operation

3. The cupola referred to in this paper is of small diameter, 35½ in., shell-lined down to 22½ in. It is operated on low blast pressure and low air volume, using fixed carbon fuel. The metal and coke charges are weighed on a scale situated on the floor level near the cupola, and are elevated and dumped into the cupola by a mechanical charging arrangement having a skip hoist and operated from the floor level.

4. The molten metal is tapped into a 180-lb. crucible hung on a trolley from an overhead monorail. This monorail connects with pouring cranes which serve all molding floors, and molten metal is taken from cupola to molds direct without transfer.

5. A platform is located on the charging door level. The operator ascends this platform occasionally to observe the progress of melting or to poke down the charge. Poking down the charge is necessary only when long gates or other bulky materials are used in the charge.

6. The cupola air blast system is equipped with a volume meter and pressure gage. The slag hole is located on the side of the cupola and the charging apparatus in the rear.

7. The section of the cupola from the bottom door to a foot or two above the melting zone is lined with a 2-inch monolithic silicon-carbide refractory backed by a coarse of firebrick and a coarse of Sil-o-cel brick for insulation. Above the melting zone. ordinary firebrick is used for lining.

Lining and Patching

8. For the monolithic lining, from 400 to 550 lbs. of silicon-carbide cement is required. This lining is good for three weeks or more, depending on the tonnage melted and the care taken in daily patching. The life of the firebrick and insulating brick backing is approximately one year.

9. The daily patching is done in the morning and requires one hour of labor. The bad spots in the lining are patched with silicon-carbide cement, requiring as a rule from 20 to 40 lbs. After the tap hole and breast are fixed up, the bottom door is swung into place and secured.

10. The bottom door is permamently lined with firebrick.

The space between the wall of the cupola and the firebrick of the bottom door is partially filled with molding sand and then a mixture of fireclay and ground firebrick. This is done through an opening in the back of the cupola. This opening is then closed from the outside by two cupola blocks.

Lighting the Bed

11. The bed charge of coke is ignited and brought to incandescence by natural draft through the open tuyeres. The blast is put on a few minutes before the first metal is charged. Approximately twenty minutes later, the metal is ready to tap.

Alloys Melted

12. Two alloys are generally melted in this cupola, either the 85-5-5-5 or the 80-10-10 alloy, or both. When changing from one alloy to the other, all the metal in the cupola is melted and drained out before the second alloy is charged. We try, of course, to run on one alloy as long as foundry conditions will permit.

Charges

13. The metal charges usually consist of alloy ingots, returned scrap and sprue and returned borings. The metal charge varies with the class of castings made. When light castings are being produced on which there is considerable machining, the amount of borings returned and the amount of sprue are greater, and the proportion of these items used is higher.

Losses

14. When melting the 85-5-5-5 alloy, the principal loss is in zinc, with practically no loss in copper, lead and tin. The metal is brought to proper composition by the addition of from 1.50 to 2.50 per cent zinc to the crucible.

15. When melting the 80-10-10 alloy, the main loss is in lead, with a slight loss in tin and practically no loss in copper. The 80-10-10 alloy is brought to proper analysis by the addition of 1.00 to 2.00 per cent lead. The loss varies with the temperature of the metal and the length of time it is held in the cupola. An extremely hot metal held in the cupola for too long a time will show a higher loss than a medium temperature metal that is tapped promptly.

16. The loss of zinc and lead is apparently by volatilization rather than by oxidation. Our experience is that loss in melting is considerably less in the cupola than in open-flame furnaces.

Size of Charges

17. A metal charge of 550 lbs. is used and the cupola holds from two to three charges, depending on the bulkiness of the materials used. The bed charge consists of 200 lbs. coke, and the average weight of coke between charges is 34 lbs.

18. The amount of coke is decreased or increased according to temperature of metal desired. The cupola will melt about ten tons per day and is operated by two men—the cupola tender and the man making up the charges.

Pouring Temperature

19. A large percentage of the castings produced consists of carburetor castings and bushings. Some of the carburetor castings are very light and are poured at a temperature as high as 2300 degs. Fahr.

20. The cupola takes the place of oil and gas-fired crucible and open-flame furnaces formerly used. A few of the crucible and open-flame furnaces still are in use for melting aluminum, manganese bronze and other alloys, the demand for which is comparatively light and in small quantities at any time.

Advantages of Cupola Melting

21. Some of the advantages of cupola melting are:

(a) Rapid and economical melting.
(b) Ease and ability to get hot metal.
(c) Absence of heat and noise.
(d) Absence of fumes (except when tapping).
(e) Low melting loss.
(f) High quality of product and clean, solid metal.
(g) Ability to melt efficiently borings, turnings, spillings, skimmings, washings, insulated copper wire, etc.

22. The cupola is not recommended for melting alloys high in zinc content.

DISCUSSION

MEMBER: What fuel ratio does the author get and what fluxes are used, if any?

T. MAULAND: The fuel ratio depends on the amount of metal melted. On a seven to ten ton heat the fuel ratio is about 15:1. On a lighter metal the ratio would be lower. A little limestone is used as flux.

F. L. WOLF:[1] What do you consider a low melting loss?

T. MAULAND: I consider anything under two per cent a low melting loss.

F. L. WOLF: Do you get under two per cent loss in the cupola?

T. MAULAND: I calculate the actual melting loss at two per cent or a trifle under. An accurate and satisfactory melting loss test is difficult to make, and thus far we have not made such tests on this cupola. The two per cent loss is estimated from charging metal of known composition and calculating loss from the analysis of the product.

Our total foundry loss is four and one-half per cent. This includes dirt, oil, iron, cutting compound, etc., in metal charged, melting loss in melting and all other losses in the foundry. This loss is lower than the loss formerly obtained when using open-flame furnaces.

CHAIRMAN J. W. BOLTON:[2] The question brought up by Mr. Wolf is one that certainly is of interest to those who contemplate the possibility of the installation of a furnace of this type.

R. LUSK:[3] We have operated one of these cupolas for a year and a half, and we find that a cupola is satisfactory if one can get a continuous melt. We get a melting ratio of 17:1. As a lining we use carborundum backed by furnace-rammed lining. I find the cupola very satisfactory for the amount we melt, which is fifteen tons per day.

MEMBER: What kind of coke does Mr. Mauland use? Has he ever used Connellsville coke, or other kinds of coke?

T. MAULAND: We use what is called "fixed carbon fuel." We have never tried other forms of coke.

F. L. WOLF: Why could not ordinary petroleum coke be used? That is practically ordinary fixed carbon coke. Also, there is considerable difference in price, I understand.

R. LUSK: When one of these special cupolas is purchased, one must enter into a contract with the people who sell it, to use that special coke.

I find that we get much higher tensile strength out of the cupola-metal test bars than we do out of the open-flame furnace which we run. On an 85-5-5-5 alloy we get 32,000 to 34,000 lbs. per sq. in. strength. On

[1] Chief Engineer and Technical Superintendent, Ohio Brass Company.
[2] Metallurgist, The Lunkenheimer Company, Cincinnati.
[3] Foundry Foreman, Mueller Company, Decatur, Ill.

our returns of gates and sprues, we get a higher tensile strength out of the cupola metal than from the open-flame furnace metal. On similar composition metal, there is about two thousand pounds difference.

R. L. BINNEY:[4] I would like to ask as to the advisability of putting in this type of melting equipment for the sake of reclamation work only. We have fifty to sixty tons that we have been accumulating for quite a while, and due to our special process we do not want to melt it except for reclamation purposes.

If you were going to melt nothing but slag, dross, skimmings and low grade material, would the loss still be low? Also, would you get from that a clean product so that it would be worth while to set up a furnace in order to reclaim the metal; and can you feed it into the furnace without putting it through a concentrator and washing it?

R. LUSK: I have had some experience with that problem, where we had approximately 35,000 lbs. of concentrates—cables, wires and similar materials. We concentrate with a magnet first. However, a great deal of lime must be used in order to get a fluid slag; if this is not done to cut the slag, it will not be long before the cupola is plugged up.

R. L. BINNEY: What is the nature of the final product?

R. LUSK: It is clean; but one must use a great deal of lime to run the slag out, otherwise the metal will never come clean.

T. MAULAND: For reclamation work the product will vary with the material charged. If the material on one charge is of different composition from material on other charges, naturally the composition of the product will vary accordingly. The thought I am trying to put over is that if one has a large quantity of material of varied composition to reclaim, the cupola in itself is a poor mixer, and one cannot expect a uniform analysis of product unless the composition of each individual charge is the same.

MEMBER: How high a temperature can you get?

T. MAULAND: We get as high as 2300 degs. Fahr. for light castings; a few of our castings are very light and difficult to run.

MEMBER: We have operated one of these furnaces and have not found it easy to cast the 80-10-10 alloy. We have had considerable trouble with gas in 80-10-10, and it counts up.

R. LUSK: Cut your coke down.

MEMBER: We have never gotten the fuel ratio that Mr. Lusk has unless we were running on reclaimed material.

R. LUSK: I keep a record of the amount of coke that I use every week, and the amount of metal we melt, and that is where I get the ratio, because I must turn that record in to the cost department and they keep a record of the operation.

In reclamation work, I would advise a much larger slag opening.

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[4] Vice-President, Binney Castings Company, Toledo, Ohio.

MEMBER: I might suggest that in reclamation work we add a small amount of iron oxide, which makes the slag more fluid.

E. F. HESS:[5] Mr. Mauland, what is your tonnage on a lining? You say that your lining lasts two or three weeks. Of course, if you run a great deal of metal through in two or three weeks, your tonnage would vary.

T. MAULAND: Figured on a melt of eight to nine tons per day, this would be from 95 to 140 tons per lining.

MEMBER: We have obtained as much as 785,000 lbs. out of one lining.

[5] Foundry Superintendent, Ohio Injector Co., Wadsworth, Ohio.

Report of A. F. A. Committee on Survey of Methods of Determining Molding Costs

MEMBERS OF AMERICAN FOUNDRYMEN'S ASSOCIATION:

Our Committee was organized under the auspices of the A. F. A. Committee on Foundry Costs. The objective given was that of making a survey of practices followed by foundries in order to see if any scientific methods were in practical use for determining direct molding labor rates, time or cost.

In order to gather data on this subject, it was necessary to send out a questionnaire to foundries and to ask the cooperation of district foundry associations.

In our original inquiries there was considerable misunderstanding as to just what we were attempting to find out. Many of the foundrymen who received our first letter sent in replies describing an entire cost system and others criticized us very severely for attempting to set up an independent cost-finding committee after all the committees in the various other foundry groups and the A. F. A. had already been at work for ten years.

We want to make it clear now that our investigation is in no way in conflict with any of the cost work that has already been done. We are not interested in molding costs as being all-inclusive; we are interested only in the cost of making the mold. We even want to correct that and say that what we are interested in is the *labor* cost of making the mold, because the molding price or the molding rate or the molding time is the basis of arriving at an estimated cost in most, if not all, of the present recognized cost systems.

We have developed very elaborate methods for determining our records and determining our costs, but a great many of us still are guessing at the molding price.

The committee did not attempt to select or recommend or attempt to define a good system. We sent out a questionnaire only to attempt to determine what was being practiced and whether any foundries were attempting to calculate molding rates instead of guessing.

NOTE: This report and the two appendixes which accompany it were presented and discussed before the cost session at the 1931 convention of the American Foundrymen's Association.

Table 1

QUESTIONNAIRE AND SUMMARY OF RETURNED INFORMATION

(1) Who in your organization estimates what the molding time or the molding piece work rate will be on a job before it goes into the sand?

Estimator	25	Foreman	55
Cost dept.	12	Time study man	40
Superintendent	73		

(2) Who establishes the standard hour basis or piece work price when the job goes in the sand?

Cost dept.	17	Time study man	40
Superintendent	64	Estimator	1
Foreman	48		

(3) Is the estimate or the actual basis set on the basis of the
judgment of an individual or department.....25,
on your experience with similar jobs.....73,
and if so, from memory.....14,
or from actual record.....87,
or on predetermined factors.....78, such as the size of the mold, etc. ?

(4) If the last named, what factors are considered?

(a) Volume of sand	65	(f) No. of chaplets	57
(b) Weight of sand	22	(g) No. of gaggers	46
(c) Size of flask	107	(h) Type of pattern	96
(d) No. per mold	87	(i) Crane bay or hand molding bay	50
(e) No. and size of cores	97		

(5) After making an estimate, do you check the actual price paid or the actual time against your estimate?

Yes	120
No	10

(6) Does the size of the run or the order affect the standard hour basis or the piece rate established?

Yes	80
No	50

We sent the questionnaire to a selected list of A. F. A. members, and we received 196 replies. Seventy of those foundries, or 35 per cent replying, have, in our judgment, a system. We want to reserve our statement simply to naming it a system, without qualifying it as to its practical use or its application in a uniform way. Thus, 70 foundries have an attempted system.

The other questionnaires sent in indicated to us that the balance of the foundries, who comprise 65 per cent of the inquiries, are guessing. When we say "guessing," we mean that they have no definite method of calculating accurately what the molding rate should be.

We do not doubt but that a great many of the guesses are better than some of the calculated rates. Nevertheless, they are in every sense of the word a rate fixed through the judgment of one or more individuals. While they have considered, consciously or unconsciously, many of the angles that the systematic plan records, they still are using their judgment based on experience without any definite calculation.

The questionnaire is shown herewith as Table 1, together with a tabulation of the replies received to the various questions. Following this report there are included four reports and papers giving more detailed information on methods used.

Of these latter, the report on methods followed by the Tri-City plants (Appendix A, page 619) should prove well worthy of study. In our opinion, 18 per cent of the foundries reporting in that group had attempted working systems.

The report by Mr. Sherwin (Appendix B, page 634) gives quite complete information on the methods used by the Brown & Sharpe Mfg. Co. foundry in setting rates. The paper by Mr. MacNeill (page 645) gives a clear idea of the procedure followed in using the point system originated by the Malleable Iron Research Institute. Mr. Harrison's paper (page 650) describes a method of scientific rate setting in foundries.

The Twin City Foundrymen's Association organized a special committee to make a survey of the practices of the Minneapolis-St. Paul district. Thirty-two foundries submitted data. The tabulation of prescribed questions and replies was as follows:

(1) Does the foundry foreman or superintendent estimate molding costs? *9 foundries replied "yes."*

(2) Do you have an estimating department which sets these costs? *8 foundries replied "yes."*

(3) Do you use a combination of both methods as listed in 1 and 2? *8 foundries replied "yes."*

(4) Have you a mathematical guide which you use?

7 foundries replied "yes."

The reply of one foundry to the questionnaire, giving detailed information, is thought to be of general interest and is given below, the question numbers referring to those shown in Table 1:

Question No. 1:

"Our superintendent and foreman, with the help of the Cost Department, estimates what the molding time or the molding piece work rate will be on a job before it goes into the sand. This, of course, applies to all work that has not been made before, and of which we have no actual cost figures."

Question No. 2:

"The same set-up is used to establish the standard hour basis or piece work price when the job goes into the sand."

Questions No. 3 and No. 4:

"This question can be answered in several ways. On new jobs, the experience and knowledge of the above set-up is used to estimate; on jobs that have been made before, actual cost figures are used.

"Of course, all things are taken into consideration, such as our experience with similar jobs and from actual records obtained in that way; the size of the mold; character of the casting; cores, if any, and the making and fitting of the cores. However, from the writer's intimate acquaintance with the members of the Newark Foundrymen's Association, especially those in the cost group, the above would apply to all foundries.

"As soon as a job is made, actual figures are obtained. The job is studied and a careful check is kept on the operations. Volume of sand; size of flask; number of castings per mold, or the weight per mold; number and size of cores; chaplets, if any; gaggers, if any, and the type of pattern equipment, must all be taken into consideration either in estimating or when actual figures are obtained.

"Also, the method of making the particular job must be taken

into consideration. For instance, if made on the floor, the approximate space is considered, whether the job must be made entirely by hand, or partly by machine, or all by machine; if it is a piece work job; if it is a gated job, or a plated job, or a loose pattern. Experience has taught us that it is absolutely necessary to take all these facts into consideration, and we think this answers question No. 4 as well as question No. 3."

Question No. 5:

"After making an estimate, if we are successful in getting the job, the actual costs are taken into consideration. These are checked against our estimate so as to have intelligent figures and to be able to determine if the castings can be made for less next time the job comes up or if we must get a higher price. This is taken care of by our cost clerk, from actual information obtained from superintendent and foreman."

Question No. 6:

"The size of the order naturally affects the number of molds that can be produced in a given number of hours, whether on an hourly basis or piece work, but past experience has shown us that this is somewhat limited. It does not mean that one can continuously decrease price by having increased orders, eventually making the castings for nothing or even paying the customer for the privilege of making the castings. This can be determined only from the experience of the first order or two, and when the maximum quantity for any day's work is established, the minimum price based on this also is established, regardless of how much larger the next order might be.

"In your letter you tell us that you are particularly interested in how we determine the direct molding cost or the piece work price. For illustration, let us suppose that the job in question is a plate with two patterns on it. The weight of the two castings is 10 lbs. If the maximum production is about 100 molds and the piece work rate, let us say, is 7½ cents, we then determine the direct molding cost as three-fourths of 1 cent per pound. To this must be added the indirect cost, then the direct core cost, which also is determined by the number of cores that can be made per hour. To this must be added the indirect core cost, and then the melted iron and cleaning cost. After a total cost has been

obtained gotten up in this way, then it is naturally up to the foundry to add whatever they think is fair as a profit and loss item, based on the tonnage per day produced, which in this case would be 1000 lbs."

Another large foundry submitted a table (Table 2) which has been computed through data obtained by time studies of various operations for molding, pouring and dumping. This refers to shop and small flask work in their nonferrous foundry. Fig. 1 is a reproduction of a price card which is extended to show their method of building up costs. Reverse side of the card (not shown)

Table 2

PIECE-WORK PRICES—STRING SCHEDULE FOR SAND BIN AND CONVEYOR MOLDING MACHINES

Pieces per Flask†	Flask Sizes* 10 X 18 Mold.	Pour.	Dump.	14 X 14 Mold.	Pour.	Dump.	16 X 16 Mold.	Pour.	Dump.	13 X 18 Mold.	Pour.	Dump.
1	3.68	0.80	1.28	3.80	0.80	1.50	4.00	0.90	1.55	4.00	0.90	1.55
2	1.84	0.40	0.64	1.90	0.40	0.75	2.00	0.45	0.775	2.00	0.45	0.775
3	1.23	0.267	0.426	1.265	0.267	0.50	1.33	0.30	0.515	1.33	0.30	0.515
10	0.368	0.08	0.128	0.38	0.08	0.15	0.40	0.09	0.155	0.40	0.09	0.155
12	0.306	0.067	0.107	0.317	0.067	0.125	0.334	0.075	0.129	0.334	0.075	0.129
14	0.263	0.057	0.092	0.272	0.057	0.107	0.286	0.064	0.111	0.286	0.064	0.111
26	0.142	0.031	0.049	0.146	0.031	0.058	0.153	0.035	0.06	0.153	0.035	0.06
28	0.131	0.029	0.046	0.136	0.029	0.054	0.143	0.032	0.056	0.143	0.032	0.056
36	0.102	0.023	0.036	0.106	0.023	0.042	0.111	0.025	0.043	0.111	0.025	0.043
38	0.097	0.021	0.034	0.10	0.021	0.04	0.105	0.024	0.041	0.105	0.024	0.041
46	0.08	0.017	0.028	0.082	0.017	0.033	0.087	0.02	0.034	0.087	0.02	0.034
48	0.077	0.017	0.027	0.079	0.017	0.031	0.083	0.019	0.032	0.083	0.019	0.032
50	0.074	0.016	0.026	0.076	0.016	0.03	0.08	0.018	0.031	0.08	0.018	0.031

* Data on flask sizes 11 × 18, 12 × 14, 13 × 15 and 13 × 17 not shown, although they were given in the original chart from which this table was prepared.

† Above table gives data only on a representative number of pieces per flask, in order to give a general idea of the method employed. In the original chart data were given for 1 to 50 pieces per flask.

is used as a piece price record for which credits are rendered as work is performed. It will be noted that on this card they use a copper differential which, in the example shown, is figured through on an 18 cent per lb. copper base, with a 13, 12 and 11 cent price shown and adjusted downward.

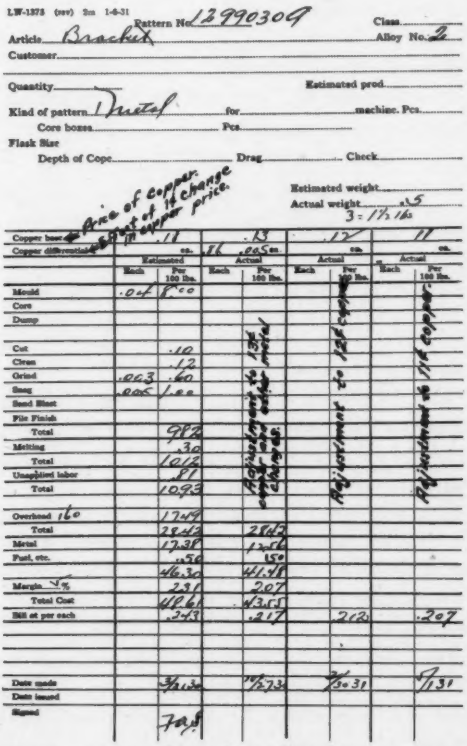
Another foundry, in addition to checking the questionnaire, reported as follows:

"To clarify our practice and method of making estimates, we present a brief outline, as follows:

"Our estimator, on each and every inquiry and after interviewing the foundry foreman, core room foreman and pattern

shop foreman, and after obtaining any other information which we might have in our possession relative to the inquiry in question, prepares and submits to our cost department the estimated pounds of good castings produced by the molder for a day's work, stipulating whether day work or piece work, and the amount of metal to pour. Also, he stipulates number of core hours required to produce the above production, and from this information the cost department figures the cost of the following:

"Mixed metals.
Oxidation, metal loss, and melting.
Direct molding labor.
Overhead on direct molding labor.


LW-1375 (rev) 2m 1-6-31

Pattern No. 12990309 Class

Article Bracket Alloy No. 2

Customer

Quantity Estimated prod.

Kind of pattern Metal for machine. Pcs.

Core boxes Pcs.

Flask Size

Depth of Cope Drag Check

Price of copper almost at its change in copper price.

Estimated weight

Actual weight 3 = 17½ lbs

	Estimated		Actual		Actual		Actual	
Copper base	.11		.13		.12		.11	
Copper differential	cts.	.16	.005 cts.		cts.		cts.	
	Each	Per 100 lbs.	Each	Per 100 lbs.	Each	Per 100 lbs.	Each	Per 100 lbs.
Mould	.04	4.00						
Core								
Dump								
Cut		.10						
Clean		.12						
Grind	.003	.60						
Snag	.005	1.00						
Sand Blast								
File Finish								
Total		9.82						
Melting		.30						
Total		10.12						
Unapplied labor		.91						
Total		10.93						
Overhead 160		17.49						
Total		28.42		28.42				
Metal		17.38		12.56				
Fuel, etc.		.50		.50				
		46.30		41.48				
Margin 5%		2.31		2.07				
Total Cost		48.61		43.55				
Bill at per each		.243		.217		.262		.207
Date made		3/12/30		11/27/30		7/30/31		9/1/31
Date issued								
Signed		Jas						

Replacement to 12% copper

Replacement to 11% copper

Fig. 1—Reproduction of a Price Card, Extended to Show Method of Building Up Costs. Size of Original Card, 5 × 8 Inches.

Direct core making labor.
Overhead on direct core making labor.
Overhead tonnage cost for finishing and shipping.

"These seven items of cost usually furnish our complete cost per ton, broken down to a unit pound figure. Where the job calls for special equipment and pattern work, these items are taken care of additionally.

"We are operating a cost system which furnishes us with departmental costs covering the four major departments, namely, Melting, Molding, Core Making, and Shipping and Cleaning.

"In our molding department we classify our product under the following sub-divisions:

"Floor Work—Hand.
Floor Work—Machine.
Bench Work—Hand.
Bench Work—Machine.
Cores all made by hand and all day labor.

"We have not as yet undertaken to ascertain cost on the milling, grinding, chipping, sand blasting and shipping by operations but we are contemplating doing so."

A malleable foundry added the following comments:

"Direct labor rates are established by the superintendent from comparison with similar jobs that we have run previously, or, if we do not have any record of a similar job, based on his judgment of production to be obtained.

"After establishing these direct labor rates, they are used on the estimate card (Fig. 2) for use in computing total costs. Percentage overheads are used departmentally and are based on direct labor in that department. These percentages are established on figures covering a number of months' operations and are changed from time to time as operating conditions indicate a change. However, because of using an average for several months in establishing percentage overheads, they do not fluctuate widely.

"The reason why two items are shown in 'General Administrative Overhead' is because they have been split up to show fixed charges and administrative overhead, experience having shown that this gives a better method of applying overhead, as all parts should not carry a flat overhead per ton charge.

"The estimate card is as close to an advance cost card as we

can get it, and after jobs are run, actual costs may be placed in the next column to check actual costs with those estimated.

"We have found the estimate card to be especially desirable, as all data pertinent to estimating are on the card. They have proven of great value when a part may be estimated again after several months have elapsed. These cards are filed carefully and every

Customer _____ Date _____

Part No. _____ Part Name _____

No. Pcs. _____ Pcs. Per Mold _____ No. Molds _____

Wgt. Each _____ Wgt. Per Mold _____ Total Wgt. _____

Molding Price { Est. _____ / Act. _____ } Core Prices { Est. / Act. }

1	2	3	4

Molds Per Day { Est. _____ / Act. _____ } Tonnage Per Day { Est. _____ / Act. _____ } Sales Value Per Day { Est. _____ / Act. _____ }

Equipment _____

Molding - Direct			
Molding - O. H. %			
Core - Direct			
Core - O. H. %			
Hard Iron			
Grind Direct			
Grind Overhead %			
Anneal			
Clean			
Inspection			
Finish			
Gen. Adm. O. H.			
Gen. Adm. O. H. %			
Commission %			
Metal			
Freight			
Total Cost Per Ton			
Profit Per Ton			
Sales Price Per Ton			
Sales Price Per Pound			
Unit Cost			
Sales Price			

FIG. 2—ESTIMATE CARD FOR USE IN COMPUTING TOTAL COSTS. SIZE OF ORIGINAL CARD, 9 × 7 INCHES.

estimate made is figured on them, so that we always have a detailed record of costs estimated and prices quoted. Any information we may be able to secure on the part, such as source, prices being paid, finish required, etc., that may be of value on future estimates, is noted on the back of the card."

Another plant reporting states that they have a time study

department which sets the rates, and that they have graphic charts made up for all the elements of time it takes to complete a mold. The standard time study form is shown in Fig. 3.

As chairman of this committee, and in concluding our report, I wish to acknowledge the very kind help of Mr. MacNeill of the Federal Malleable Iron Co.; Mr. Harrison of Stevenson, Jordan & Harrison; Mr. Weiland of the Milwaukee Grey Iron Foundry Co.; Mr. Sherwin of Brown & Sharpe Mfg. Co., and of Mr. Brah of the Quad City Foundrymen's Association, as well as to thank the many foundrymen who submitted not only replies to our questionnaires but complete data on their methods.

Respectfully submitted,

WM. J. GREDE, *Chairman.*

COMMITTEE ON SURVEY OF METHODS
OF DETERMINING MOLDING COSTS.

OBSERVATION SHEET

OBSERVER'S NAME _____ MACHINE No. _____ STEEL FLOOR DATE _____ 19__

WORKMAN'S NAME AND QUALIFICATIONS _____ COPE

MADE IN _____ DRAG

PIECE _____

AREA _____ SQ. FT. _____ VOL. _____ CU. FT.

	DETAIL OPERATIONS																									
		OBSERVATION TIME																								ALLOWANCE TIME
1	LEVEL FLOOR																									
2	SET BOARD																									
3	SET DRAG																									
4	SET PATT.																									
5	PARTING SAND																									
6	FACE COPE AND DRAG																									
7	SCOOP AND RAM																									
8	STRIKE OFF																									
9	LEVEL, BOARD, CL. AND ROLL																									
10	PARTING																									
11	BLOW																									
12	PARTING SAND																									
13	SET COPE																									
14	SET GAGGERS																									
15	GATES AND RISERS																									
16	STRIKE OFF																									
17	LIFE COPE																									
18	BLOW																									
19	RAP AND DRAW																									
20	PATCH COPE AND DRAG																									
21	BLOW																									
22	SET CORES																									
23	CLOSE																									

MIN. TIME IN MIN. _____

\+ _____

TOTAL TIME IN MIN. _____

TOTAL TIME IN HRS. _____

BASE RATE _____

RATE SET _____

STUDIED BY _____

COMPUTED BY _____

APPROVED BY _____

FOREMAN O.K. _____

METHOD O.K. _____

SUPERINTENDENT O.K. _____

FIG. 3—STANDARD TIME STUDY FORM. SIZE OF ORIGINAL CARD, 4 × 6 INCHES.

APPENDIX A

Survey of Methods for Determining Molding Prices in the Quad City District*

SUMMARY OF SURVEY

The findings of the committee of the Quad City Foundrymen's Association on "Methods Used in Determining Molding Prices," disclosed a number of different methods, some of which are similar in fundamental principle but differ in detail. The point system† is most commonly used by firms following any systematic course. While comparison and experience are not to be criticized, it is felt that some unit of measurement can be applied and will offer a medium of arbitration when the prices happen to be disputed by the molder.

The cubical content of the flask is used as a base in most instances, while in one case the weight of the mold forms the base. Points are awarded for various operations and later reduced to a monetary value in all but one exception. Here we find the unit of award of ¼ cent values, with multiples of this amount for various operations. The chief advantage results in the easier explanation to the molder in case of dispute.

In one isolated case, we find the prices have been set many years ago by a committee for this purpose. Changes have been made from time to time in adding or subtracting a percentage to or from this base price. The chief disadvantage lies in the fact that a single job cannot be treated individually; changes are made to affect the entire production at one time. This may or may not work an injustice in the price of certain jobs.

While time study has been mentioned in several cases, it must be clearly understood that this can be used only after the job is in production. The figures then are available for comparison purposes on further bids.

In conclusion, we note that the point system has been applied to squeezer and bench jobs alone, while other machine work has not been so treated. Apparently, it is only a matter of study to make this same system applicable to any production job, whether the work is performed on the Arcade, the jolt or on some similar machine.

* Survey prepared by committee of the Quad City Foundrymen's Association.

† See paper by W. J. MacNeill, *The Point System for Determining Molding Piece Rates*, in this volume of TRANSACTIONS, page 645.

We take this opportunity to thank the members of this association for their cooperation in this and past undertakings, and sincerely hope that you profit in return.

QUAD-CITY FOUNDRYMEN'S ASSOCIATION
S. M. BRAH, *Chairman.*
CLYDE BURGSTROM
OSCAR CHRISTOFFERSON
JOHN JONES
A. D. MATHESON
M. RICHESON
Committee.

Detailed data obtained by the above-named committee from various foundries of the Tri-Cities are given below.

METHOD AND EXPLANATION

Plant No. 1.

Following are determining factors in setting new molding prices:

(1) Quantity of molds to be made.

(2) Cubical sand content of mold.

(3) Whether job is to be made bench, floor, or power squeezer.

(4) Type of pattern, whether on plate, hard match, follow board or loose pattern, and how hard same is to draw out of sand.

(5) Our equipment.

(6) Number of castings on pattern.

(7) Weight per mold.

(8) If casting is cored, and how many cores to set.

(9) If hinge tubes or chaplets are used, and how many per mold.

(10) Possible number of molds that can be put up in a 7-hour day.

(11) References to jobs of like characteristics are also made as a checking medium.

(12) Time studies are generally made with a stop watch on pattern with runs over 500 molds.

Plant No. 2.

This firm has tried the uniform cost system and has rejected it as unsatisfactory for their plant.

The manager of the plant estimates the number of molds that the man who is going to run the job will put up, gets the total weight of the floor, and divides the amount of revenue that this floor should return by the number of castings produced, which gives him the price per pound of the casting.

Plant No. 3.

Method used for setting piece rate prices is to take size of flask used, number of men to run the job, and number of estimated molds per hour.

Prices usually are set from experience with similar jobs using same flasks and number of men on the job.

Plant No. 4.

Schedules used in figuring molding prices and examples of Squeezer and Bench jobs:

Molding

Plate, squeezer and bench rates based on 12, 17 and 25 points, respectively; sand figured at 30 points per 1000 cu. in. in mold, and over 2000 cu. in. 50 points per 1000.

Example:

1500 cu. in. .....45 points

2000 cu. in. .....85 points { 2000 @ 30 / 500 @ 50

Cubic contents of flask figured thus:

Length × Width × Depth.

For every small core dropped, allow 1 point per core. Set 2 points per core.

Moderate core.....	3 points	Additional gate.....	2 points
Large core.....	4 points	Frame pattern, gate..	14 points
Large complex core...	8 points	Additional gate.....	2 points
Chills drop.....	1 point	Hand pattern, gate...	17 points
Chills set.....	2 points	Additional gate (dupl.)	4 points
Bands	3 points	Additional gate (diff.)	6 points
Plate pattern, gate....	12 points	Hand pattern, bench..	20 points

Special features are determined by foreman or timer.

In concluding, add points and multiply by base rate to arrive at job price:

Basic, Squeezer 0.60

Basic, Bench ..... 0.80 7½ hours molding.

Example:

Bench job—1 in. mold; flask 10 × 24 × 7.

2 chills—8 nails—2 med. cores—2 small cores.

Close inspection on this job, demanding good castings.

Points:

Bench base (hand pattern).....	20.0 points
Flask 10 × 24 × 7, equals 1680 cu. in. sand, at 30 points per 1000.....	50.4 points
2 chills, @ 2 points each.....	4.0 points
8 nails, 1 point each.....	8.0 points
2 med. cores, 3 points each.....	6.0 points
2 small cores, 2 points each.....	4.0 points
Allowance 7 points (inspection).....	7.0 points
Total	99.4 points

Total of 99.4 pts. × basic bench hourly rate of 0.80, equals 99.4 × 0.80 = 7.95 per 100 molds.

Note: All base rates assumed.

Plant No. 5.

Estimate of molding time is made by the foreman. Time study made of job and a bonus paid to encourage efficiency.

Plant No. 6.

Prices are established in the foundry by comparison and time study, according to knowledge of foundry superintendent and foreman.

Plant No. 7.

Rates are set through conference of foundry superintendent, pattern foreman, production manager and molder who will work job. Final production price is established through time study and further conferences.

Plant No. 8.

Comparison and estimate of foundry foreman is basis for setting rates.

Plant No. 9.

Point system of setting molding prices is used.

(1) *Points:*

Hand pattern, bench, single gate	20	points
Plate pattern, bench, single gate	17	points
Hand pattern, squeezer, single gate	15	points
Plate pattern, squeezer, single gate	12	points
Additional gates	2	points each
Small drop cores	1	point each
Small set cores	2	points each
Medium set core	3	points each
Large set core	4	points each

Large complex core..... 8 points each
Chills drop ..... 1 point each
Chills set..... 2 points each
Cu. in. of sand per 1000.....30 points each

(2) Special features determined by foreman and timer.

(3) In conclusion, add points and multiply by base rate to arrive at job price.

(4) Base rate, squeezer..... .80
Base rate, bench..... .90

(5) *Example:*

Squeezer plate double gated, four pieces in a mold, flask 11 × 17 × 6½, four small cores set in pattern, cope side, four medium cores set in drag.

Points:

Squeezer base plate pattern.....12 points
Double gated..... 2 points
Flask 11 × 17 × 6½—1216 cu. in. @ 30 pts. per 1000.....36 points
4 small set cores, 2 pts. each..... 8 points
4 medium set cores @ 3 pts. each.....12 points

Total .....70 points

No allowance made.

Multiply total points by basic squeezer rate:

70 × .80 equals $5.60 per 100 molds.

Plant No. 10.

Molder paid by the hourly rate. Castings are quoted by comparison. Special alloys, permitting very high prices per pound, protect shop against losses.

Plant No. 11.

The following method of figuring prices paid for molding is used on continuous conveyor system where the greater part of the sand is handled into the flask mechanically and is then rammed either with hand rammer, shovel or air rammer. Solid steel flasks

are used entirely. The various operations and motions for the making of the molds being practically the same for all size flasks, the main difference is that one flask is heavier than the other on account of the amount of sand to be rammed and handled. Therefore, the weight of the complete mold (including bottom boards, flask, sand and core) is used as the basis for determining prices.

A based weight is taken on the smallest flask used and a price per 100 molds is set for this weight. This price includes labor of placing the flask in position on the pattern, filling the flask with sand, ramming, drawing, closing the molds and lifting same on the conveyor.

For each additional pound over the base weight, a definite price per pound per 100 molds is added to the base figure. For all additional motions required for making certain molds, a definite price per motion per 100 molds has been set. The following additional motions are recognized and paid for:

Setting cores { center cores. / ring cores. / bolt or spoke cores.
Tucking cores.
Gaging cores.
Drawing loose bosses.
Turning drag.
Venting molds.
Second sprue pin or riser.
Cutting riser.
Wiring cope core.
Setting chills.

The price per 100 molds for all the above motions and operations is determined by time study and then can be applied to all sizes of flasks made on this particular molding unit.

The same system of prices can be used on the bench or floor if the same types of flask are used, with additions to the price to cover carrying out molds, pouring and cutting sand if the molder should cut his own sand.

Pouring of molds is paid on a tonnage basis of good castings.

Plant No. 12.

Prices are established in the foundry by comparison and

time study, according to knowledge of foundry superintendent and foreman.

Plant No. 13.

Time study and comparison are used in setting rates. No occasion to arrive at molding costs until job is started, as all castings are consumed in the production departments of this plant.

Plant No. 14.

To determine molding prices on new work, the following methods are used:

(1) Comparison.
(2) Point system (as shown below).
(3) Foundry superintendent and foreman's knowledge.

Schedule for Determining Molding Rates

It was assumed at the outset that any molding price was made up of a series of items which would be predicted from some characteristic of the job.

One part of the price would be proportional to the amount of sand handled. Another to the cores and chills set. Another to the amount of iron poured; and another, covering handling of the flask and pattern, would be nearly constant except as there might be more than one gate of patterns in the mold.

It was assumed further that, as labor rates varied with time and locality, prices would vary but all in the same proportion.

It now is apparently applicable to any reasonable run of bench or squeezer molds, regardless of whether the pattern is hand or plate. As at present employed, the calculations are as given below, the factor for any mold being set up as follows:

30 pts. for each 1000 cu. in. of flask content.....Sand handling.
50 pts. for each 1000 cu. in of flask content above 2000 cu. in.....} For over-size flask.

1 for each chill dropped in place.....
2 for each chill carefully set..... } For chills.
2 for bands in mold,..... For bands in molds.
1 for each small core dropped in.
2 for each small core set.....
3 for each moderate size core.... } For cores.
4 for each large core..... } Discount these allowances if
8 for each large complex core.... } cores run over 4 of a kind.
12 for plate pattern, one gate.....
2 for each addtl. gate.....
14 for frame pattern, one gate.....
2 for each addtl. duplicate gate.....
17 for each hand pattern, squeezer.... } For handling equipment.
4 for each addtl. duplicate gate.....
6 for each addtl. different gate.....
20 for hand pattern, hand rammed....
4 for each addtl. gate.....
6 for each addtl. different gate.....

The sum of these items, expressed in cents, represents the relative value or factor for the particular job and set-up.

To reduce this price to a price per 100 molds, it must be multiplied by a coefficient depending upon the average earnings per hour deemed necessary for piece workers. For example, if the factors for sand handling, cores and pattern equipment totaled 60, and the wage ruling in the shop is $1.00 per hour, the price per 100 molds would be $6.00.

This does not include pouring, which would be extra.

Figured approximately 1½ hours per 9-hour day.

Plant No. 15.

Schedule for Determining Molding Rates.

Sand Handling:

Sand for the first 1000 cu. in. of flask content, 2.35; add 1/10 of 1 cent for each additional 100 cu. in. of sand over 1000 cu. in.

Pattern draw:

For plate pattern, one sprue..... ½c
For plate pattern, two sprues..... 1c
For each addtl. on plate..... ¼c

For each hand pattern, squeezer..... ¾c
For two gates, hand pattern, squeezer.....1¼c
For each addtl. duplicate gate..... ½c
For hand pattern, bench rammed..... 1c
For 2 gates, hand pattern, bench rammed.....1½c

Core setting:

¼c per mold to ¼c per core.
1 for each small core dropped in.
2 for each small core set.
3 for each moderate size core.
4 for each large core.
8 for each large complex core.

Chills:

1 for each chill which can be dropped in place.
2 for each chill which must be set carefully.

Extras:

Bad cope, lift, nails or gaggers.....¼ to 2c
Bad draw .....¼ to 1½c

Pouring:

Heavy jobs .....½ to 2c
Pour 1 to ladle.....2c
2 to ladle.....1½c
3 to ladle.....1c
4 to ladle.....¾c
5 to ladle.....½c

Lifting:

Heavy flask (over 11 x 21).....¼ to ½c

Plant No. 16.

Rates are set by comparison with other jobs and according to knowledge of foundry superintendent and foreman. In production, the prices often are established by time study.

Plant No. 17.

We have a board price that has been established for some time. When a new job comes into production, we compare it with a job that has been in production, making an allowance for

difference in cope and drag depth and numbers of tins or doves that are used and the number and size of the cores.

We have this board price which is a rather constant figure over a period of years, and any changes in our prices are made to cover our entire production with a percentage. The board price, when a change is made, is not interfered with but remains the same, and the percentage is increased or decreased.

Note: Board price is an established price, or standard set.

Plant No. 18.

Rates are set by time study. In this plant there are no outside jobs to figure. For comparison on costs, the foreman estimates the number that can be produced.

Plant No. 19.

The weight of the casting and size of the flask is compared with similar jobs to establish the price. If the price is not right after operating a while, adjustments are made.

The foundry superintendent, plant superintendent, time study and production man meet and set prices.

Plant No. 20.

This company compares a new job with other jobs that have been run, taking into account differences in size and cores, as well as the quantity of cores.

The plant manager and foundry superintendent are the men who establish the price.

Plant No. 21.

To determine prices on new work, the following methods are used:

(1) Comparison.
(2) Point system as shown.
(3) Knowledge of foundry superintendent and of foundry foreman.

Prices are established in the foundry by comparison and time study.

Schedule for Determining Molding Rates on Bench and Squeezer Jobs.

It was assumed at the outset that any molding price was made up of a series of items which could be predicted from some characteristics of the job.

One part of the price would be proportional to the amount of sand handled; another, to the core and chills set; another, to the amount of iron handled; and another, covering the handling of the flask and pattern equipment. This is somewhat constant except for the additional gates in the mold.

Points:

The factor for any mold is made up of the following items:

30 points for each 1000 cu. in. of flask content. Cubic content is: Length × Width × Depth.

1 point for each chill dropped in place.
2 points for each chill set carefully.
2 points for each band set in mold.
1 point for each small core dropped.
2 points for each small core set.
3 points for each moderate core.
4 points for each large core.
8 points for each large complex core.
12 points for each plate pattern, single gate, squeezer.
15 points for each plate pattern, single gate, bench.
14 points for each frame pattern, single gate, squeezer.
17 points for each hand pattern, single gate, squeezer.
20 points for each hand pattern, single gate, bench.
2 points for each addtl. gate, plate.
4 points for each addtl. gate, hand.
35 points per 100—50 lb. ladle of iron.
2 to 10 points addtl. for difficult pattern drawing.
2 to 10 points addtl. for special ramming.

Special features should be determined by foreman or timer.

In conclusion, add points and multiply by base rate to arrive at job price.

Plant No. 22.

Estimate the number of molds a man can put up in one day in comparison with previous jobs with which we are familiar, or by knowledge of molding superintendent and foreman.

Plant No. 23.

Rates are determined by comparison with former jobs and by careful study of job by superintendent of foundry and molder.

Plant No. 24.

The size of flask, number of cores and chills to be set are used as a comparison against previous similar jobs in setting rates.

Plant No. 25.

Schedule used in Figuring Molding Prices and Examples of Squeezer and Bench Job

Molding: Plate, squeezer and bench rates based on 12, 17 and 30 points, respectively; sand figured at 30 points per 1000 cu. in. in mold, and over 2000 cu. in. 50 points per 1000.

Example:

1500 cu in.....45 points

2500 cu. in.....85 points { 2000 @ 30 / 500 @ 50

Cubic contents of flask is figured:

Length × Width × Depth.

For every small core dropped, allow 1 point per core. Set 2 points per core.

Moderate core	3 points
Large core	4 points
Large complex core	8 points
Chills drop	1 point
Chills set	2 points
Bands	3 points
Plate pattern, 1 gate	12 points
Addtl. gate	2 points
Frame pattern, gate	14 points
Addtl. gate	2 points
Hand pattern, 1 gate	17 points
Addtl. gate (duplicate)	4 points
Addtl. gate (different)	6 points
Hand pattern, bench	20 points
Addtl. (duplicate)	4 points
Addtl. (different)	6 points

Special features determined by foreman or timer.

In concluding, add points and multiply by basic rate to arrive at job price.

Basic squeezer	.80	7½ hrs. molding
Basic bench	1.00	

Example: Pattern D-78-R.

Bench Job:

1 in mold—flask 10 × 24 × 7.

2 chills—8 nails—2 med. cores—2 small cores.

Close inspection on this job, demanding good castings.

Points:

Bench base, hand pattern	20.0 points
Flask 10 × 24 × 7, equals 1680 cu. in. sand @ 30 points per 1000	50.4 points
2 chills set, 2 points each	4.0 points
8 nails, 1 point each	8.0 points
2 medium cores, 3 points each	6.0 points
2 small cores, 2 points each	4.0 points
Allowance 7 points	7.0 points
Total	99.4 points

Total of 99.4 points × basic bench hourly rate of $1.00, equals 9.95 per 100 molds.

Note: All base prices assumed.

Example: Pattern E-418 Sleeve.

Squeezer Job:

2 pcs. in mold—flask 10 × 14 × 6½.
2 med. cores—2 small round cores set in pattern in cope.

Points:

Sq. base, hand pattern	17.0 points
Flask 10 × 14 × 6½ equals 910 cu. in. of sand @ 30 points per 1000	27.3 points
2 med. cores set, 3 points each	6.0 points
2 small round cores set, 2 points each	4.0 points
Total	54.3 points

No allowance made for the lift or draw.

Total of 54.3 points × basic sq. hourly rate of $.80 per hour, equals $4.35 per 100 molds.

Example: Pattern Z-463 Guard.

Squeezer Plate Job:

4 pcs. in mold—Flask 9 × 17 × 6½.
4 med. cores.

Points:

Sq. base, plate pattern	12.00 points
Flask 9 × 17 × 6½, equals 994—5 cu. in. sand @ 30 points per 1000	29.83 points
4 med. cores set, 3 points each	12.00 points
Total	53.83 points

No allowance made for the lift or draw.

Total of 53.83 pts. × basic sq. hourly rate of $.80 per hour, equals $4.30 per 100 molds.

(*Continued on next page*)

APPENDIX B

Report on Foundry Price Setting System of Brown & Sharpe Mfg. Co.*

Our foundry price setting system has been built up from data obtained from a large number of time studies taken in our own foundry.

The factors obtained from these data are made up of constants and variables. The constants have been reduced to the form of a curve sheet or set of figures which takes care of all operations common to all jobs made on certain squeezer machines, molding machines, bench work or floor work.

The variables consist of such items as shovel and ram sand, place pattern and each loose piece of pattern, loose upset, clay wash or wetting flask, extra vents, risers, fasten pattern to cope to lift, placing of nails, gagger rods, chills, cores, making parting joint, drawing pattern, finishing and blacking mold, rapping pattern before lifting cope, bolt and unbolt bottom plate, build runner boxes, skin drying, drying wet blacking with torch, etc.

SQUEEZER MOLDING MACHINES

The squeezer machines are power jolts with three different kinds of pattern equipment, as follows:

(1) Gated pattern on litharge match or follow board.

(2) Gated pattern on litharge match or follow board with vibrator attachment.

(3) Gated pattern on match plate with vibrator attachment.

The first, that of gated pattern, requires time for rapping pattern before lifting off cope, and again before drawing pattern, also making a joint and watering pattern.

The second, gated pattern with vibrator attachment, requires making a parting joint but no rapping or watering of pattern.

The third, gated pattern on match plate, requires no making of joint, rapping, or watering of pattern.

* Submitted by LeRoy M. Sherwin, foundry and pattern shop superintendent, Brown & Sharpe Mfg. Co., Providence, R. I.

Molds for the squeezer machines require three different sets of constants, the variables remaining the same, except the time for finishing mold on vibrator attachment and match plate, as the pattern is drawn more true and does not require as much finish; also, the match plate requires no time for making joint.

There also are three different sets of each of the constants of different pattern equipments, such as added time for fatigue on larger sizes of flasks, which are divided into three classes: (1) Those less than and up to 160 sq. in.; (2) those with 161 to 200 sq. in., and (3) those over 200 sq. in. in flask size.

As squeezer machine work is very nearly all alike regardless of shape of pattern (except as before stated), it is governed by the square inches of flask to get the constants. The time allowed for shoveling and ramming is governed by the cubic inches of sand in flask and multiplied by a set variable, meaning the amount of time required to shovel and ram one cubic inch of sand in flask. This variable has three different amounts for squeezer work, such as (1) easy shovel and ram, (2) hard shovel and ram, and (3) shovel sand and jolt.

The variable of "joint" has three different amounts of set time for squeezer work, such as easy, medium, and hard. This is governed by the judgment of the man setting the rates, which may be questioned by the foreman of the department, who may call for the taking of a time study of the particular job. The variable of "draw pattern and finish" has three different amounts of time, such as easy, medium, and hard. On squeezer work this is a set amount of time, as almost all work of this type requires about the same amount of finish.

There is a variable for "blacking on squeezer." This item is alone as there are a number of jobs where it is not used, so it is rated in four sets of time amounts, such as none, dust, brush, and rub.

There is a sheet allotted to the setting of one or more nails; one for time of setting one or more gaggers, soldiers, or rods, and one for time of setting different grades of cores. These are used for all branches of the foundry.

MOLDING MACHINE WORK

The system for use on molding machine rates is about the same as for the squeezer on small work until the square inches of flask exceed 325 sq. in. in size. The fatigue is greater on ac-

count of handling iron and steel flasks and there are most always two rollovers, instead of one as on squeezers. This makes a larger amount of time for constants.

The time allowed for "shovel and ram" is greater, as more ramming is necessary. Therefore, the variable for multiplying the cubic contents of flask is larger.

The set time for "finish" is larger, as the area of surface of pattern is much larger on this type of machine. This is divided into three grades, such as easy, medium, and hard.

The "blacking" time also is a set time on small work on machine, and in four grades, such as none, easy, brush, and rub.

When we go over 325 sq. in. of flask area, the fatigue is greater and requires a larger constant and variable. This is taken care of by a curve sheet, one for each kind of machine, such as one-half on rollover and one-half on plate, both halves on rollover, one-half on rollover and one-half on stripper, both halves on stripper, etc. A separate sheet of constants and variables also is used on the different types of small molding machines.

The allotted time for constants on large machine work is obtained from the square inches of flask, except in case of certain jobs such as cone pulleys or any very deep flask, in which case the square inches of flask are found by multiplying the depth by the width. (So far, this method has been used only on cone pulleys in our shop.)

The "shovel and ram" time is obtained from a set variable multiplied by the cubic inch of area in flask with the cubic inches of pattern taken out. There are four variables in this item, such as very easy (plate work; no gaggers are used), easy, hard, and very hard.

The "finish and blacking" time is combined and is obtained by getting the square inches of area of pattern, including core prints and loose pieces, and using a set variable which is multiplied by the square inches of pattern area. This variable has six ratings, namely, very easy, very easy particular, easy, easy particular, medium, and hard.

The building of runners and riser boxes, use of screw clamps, binders, wedges, etc., are taken care of in the miscellaneous sheet discussed in this report under the heading "Floor Work."

In case of three-part work in all branches of the molding department, except the bench, in arriving at the time for constants the set figure or figures received from the curve sheet for

constants is multiplied by 1.5, or one and one-half times the constants. Also, there is another parting joint in this kind of work. The joint must be used two or three times, or as many times as there are parts to the flask.

BENCH WORK

Bench work is divided into four sheets (see Tables 3, 4, 5 and 6) of constants and variables.

Sheet 1 (Table 3) is for circular patterns up to a point where the diameter squared is less than 80 inches; 80 inches and over becomes what we call a "full mold" and is taken care of by the respective sheet according to size of pattern.

Sheet 2 (Table 4) is to take care of small patterns which do not require the whole flask.

Sheet 3 (Table 5) is to take care of patterns which require whole flasks whose area is less than 225 sq. in.

Sheet 4 (Table 6) is to take care of patterns which require part or all of a flask with over 225 sq. in. of area.

Sheet No. 1 lists the set time standards for constants of circular patterns, and the constants are governed by the square inches of the pattern diameter multiplied by diameter. The sheet is divided into sizes such as 10 to 15, 16 to 20, 21 to 25, 26 to 32, 33 to 39, 40 to 49, 50 to 56, 57 to 64, 65 to 72, and 73 to 79, and the standards are controlled by the parting joint of their respective size in square inches.

Each section of square inches has three different set time allowances, or constants such as easy joint, medium joint, and hard joint. These constants, like the constants of sheet 2, which will be explained later, carry the time allowance granted for placing the board and flask, striking off, placing boards on or off, venting, watering pattern, closing and fastening hooks, lifting off of cope, cutting sprues and basins, making of parting joint, and shoveling and ramming sand for their own respective part of the flask.

Except when the particular pattern or patterns are to be made three-parted, we then use sheets 3 or 4, and split the constants of such to whatever part of the mold the pattern is to carry, such as 1/4, 1/3, 1/2, 2/3, 3/4, etc. This operation also will split the variable for shoveling, ramming and making of parting joint.

The time allowance for finishing these patterns is the square inches of area of said pattern multiplied by the variable per square inch on sheets 3 or 4. Any other time amounts required, such as cores, nails, spikes, etc., are taken from the sheets which cover the same for all departments.

Sheet 2 is somewhat similar to sheet 1, except that it takes care of the other small patterns. It is divided off into sections

Table 3

CURVE SHEET 1—BENCH STANDARD FOR CIRCULAR PATTERNS ONLY, CONSTANTS ONLY. (See Table 5 for Variables.)

Flask Sizes, sq. in.	Hours		
	Easy Joint.	Medium Joint.	Hard Joint.
10-15, inclusive	0.0256	0.0310	0.0366
16-20, inclusive	0.0303	0.0366	0.0432
21-25, inclusive	0.0341	0.0413	0.0488
26-32, inclusive	0.0402	0.0488	0.0575
33-39, inclusive	0.0512	0.0620	0.0732
40-49, inclusive	0.0605	0.0732	0.0865
50-56, inclusive	0.0682	0.0826	0.0976
57-64, inclusive	0.0768	0.0930	0.1098
65-72, inclusive	0.0805	0.0975	0.1150
73-80, inclusive	0.0905	0.1100	0.1295

with three different time allowances for each size of pattern, and also each different size pattern is governed by its respective parting joint, such as: Easy joint, medium joint, hard joint; 1/4 pattern, 1/3 pattern, 1/2 pattern, 2/3 pattern, 3/4 pattern.

These pattern sizes are governed by a standard size flask of 13 × 13 square inches.

The finishing time allowance for any particular pattern is governed by its respective square inches of area, and carried through the same as explained for sheet 1.

Table 4

CURVE SHEET 2—BENCH WORK FOR SMALL PATTERNS
(All Time Stated in Hours)

Constants.

One-quarter pattern with (9 to 20)	Easy joint	0.303
	Medium joint	0.366
	Hard joint	0.0432
One-third pattern with (20 to 33)	Easy joint	0.0402
	Medium joint	0.0488
	Hard joint	0.0575
One-half pattern with (33 to 50)	Easy joint	0.0605
	Medium joint	0.0732
	Hard joint	0.0865
Two-thirds pattern with (50 to 67)	Easy joint	0.0805
	Medium joint	0.0975
	Hard joint	0.1150
Three-quarters pattern with (67 to 80)	Easy joint	0.0950
	Medium joint	0.1100
	Hard joint	0.1295
Very small extra pattern	(0 to 2.5 in.)	0.0075
Small extra pattern	No cores	0.0165
	Cores (2.5 to 6 in.)	0.0206
	Horn sprue	0.0248
Large extra pattern	No cores	0.0241
	Cores (6 to 9 in.)	0.0300
	Horn sprue	0.0346

Variables.

Place horn sprue		0.0035
Place pattern (each piece)		0.0015
Fasten pattern to cope		0.0050
Draw pattern, finish and blacken:		
	Very easy	0.00010 per sq. in.
	Easy	0.00025 per sq. in.
	Medium	0.00040 per sq. in.
	Hard	0.00055 per sq. in.

NOTE: If greatest length times greatest width is less than 2½ inches, consider as a very small extra pattern, between 2½ and 9 inches, consider as small extra pattern; between 9 and 20, consider as one-quarter pattern; between 20 and 33, consider as one-third pattern; between 33 and 50, consider as one-half pattern; between 50 and 67, consider as two-thirds pattern; between 67 and 80, consider as three-quarters pattern.

Table 5

CURVE SHEET 3—BENCH WORK FOR FLASKS LESS THAN 15 × 15 INCHES IN SIZE (ALL TIME STATED IN HOURS)

Constants.

Place board and drag	0.0070
Strike off and board on	0.0050
Rollover and remove board	0.0040
Set cope on	0.0027
Strike off	0.0028
Cut sprues and basins	0.0134
Lift off cope	0.0056
Water patterns	0.0061
Close and fasten hooks	0.0081
Set on floor	0.0035
Vent	0.0118
Total Constants	0.0700

Variables.

Place pattern, each piece	0.0020	
Place upset	0.0015	
Face pattern, shovel and ram:		
Easy	0.000025	per cu. in. of flask
Hard	0.00003	
Very Hard	0.000035	
Clay wash on cope	0.0050	
Extra vent	0.0085	
Riser	0.0093	
Fasten pattern to cope	0.0050	
Make joint:		
Very Easy	0.0075	
Easy	0.0175	
Medium	0.0300	
Hard	0.0600	
Very Hard	0.0900	
Set gaggers or soldiers	(see gagger sheet)	
Set nails	(see nail sheet)	
Set cores or chills	(see core sheet)	
Draw pattern, finish and blacken:		
Very Easy	0.00012	per sq. in. of pattern
Easy	0.00025	
Medium	0.00040	
Hard	0.00055	
Place and lift off false cope	0.0084	
Extra hooking, cut gates in cheek, place, lift off cheek and replace (3 part mold)	0.0282	

NOTE: For very difficult jobs with only one or two pieces on the order, increase time 50 per cent. For slightly difficult jobs with only one or two pieces on the order, increase time 25 per cent.

Table 6

CURVE SHEET 4—BENCH WORK FOR FLASKS 15×15 INCHES OR OVER (ALL TIME STATED IN HOURS)

Constants.

Place board and drag	0.0119
Strike off and board on	0.0061
Rollover and remove board	0.0072
Set cope on	0.0090
Strike off	0.0036
Cut sprues and basins	0.0180
Lift off cope	0.0090
Water patterns	0.0107
Close and fasten hooks	0.0142
Set on floor	0.0061
Vent	0.0180
Total Constants	0.1138

Variables

Place patterns, each	0.0040
Place upset	0.0015
Face pattern, shovel and ram:	
Easy	0.00002 per cu. in. of flask
Hard	0.00003 per cu. in. of flask
Clay wash on cope	0.0070
Extra vent	0.0085
Riser	0.0093
Fasten pattern to cope	0.0075
Make joint:	
Easy	0.0090
Medium	0.0360
Hard	0.0900
Very hard	0.1200
Set gaggers or soldiers	(see gagger sheet)
Set nails	(see nail sheet)
Set cores or chills	(see core sheet)
Draw pattern, finish and blacken:	
Very easy	0.00010 per sq. in. of pattern
Easy	0.00025 per sq. in. of pattern
Medium	0.00040 per sq. in. of pattern
Hard	0.00055 per sq. in. of pattern
Place and lift off false cope	0.0120
Bed pattern in (hard joint, no match)	0.0500
Extra hooking, cut gates in cheek, place, lift off cheek and replace (3 part molds)	0.0366

NOTE: For very difficult jobs with only one or two pieces on the order, increase time 50 per cent. For slightly difficult jobs with only one or two pieces on the order, increase time 25 per cent.

Sheet 3 is used for all flasks on the bench whose area is less than 225 sq. in. A pattern is called a "full mold" when the area is 80 sq. in. or more.

The constants are made up of time allotments for placing and removing bottom board and follow board, striking off and rolling over, cutting sprues and basins, watering patterns and lifting off of cope, rapping patterns, putting sand on, venting, closing mold, and setting on floor.

The shoveling and ramming is governed by the cubic inches in the flask multiplied by a set variable, as in other forms of molding which have been explained.

The finishing is the same as explained for the circular and part patterns—square inches of pattern area multiplied by set variable. On three-part work on the bench, there is a variable for an operation which we call "three-part hooking." This is used instead of multiplying of constants as stated in other parts of foundry work; also, there is another joint to be added according to nature of the pattern.

Sheet 4, on bench work, covers the time allowance on flasks used on bench whose area is over 225 sq. in. This sheet is the same as 3, except that the time allowances are larger on the constants and variables to take care of the extra fatigue for heavier work.

FLOOR WORK

Floor and crane work is a little different from the other branches of molding, the time constants being obtained by the square inches of area of flasks and nature of the parting joint of pattern to be used.

There are three curve sheets for constants, namely, easy joint, medium joint, and hard joint; and one curve sheet for large flasks of 4000 square inches and over. This latter sheet has three curves on it, the easy joint, medium joint, and hard joint, classed as A, B, and C.

An easy joint is when we have a split pattern or pattern which has a flat surface on the cope side and the parting joint is even with the joint of the flask.

A medium joint is when the pattern has a rounded edge or uneven parting joint such as the arms of a wheel, etc.

A hard joint is when the line of parting joint is very uneven

and there are banks to secure with spikes, etc., when wet parting sand has to be used in order to make a good parting.

The constants, therefore, take care of the time allowance for making the parting joint, handling of mold board and bottom board, all parts of flask, rolling over, parting sand, rapping and watering patterns, lifting off of cope, and closing mold.

Shoveling and ramming time is derived by multiplying the cubic inches of sand in flask, less the cubic inches of pattern taken out, by a set variable per cubic inch.

There are different kinds of ramming, namely, by hand, by sandslinger, and by bumper.

By hand, there is a variable for easy and hard.

By sandslinger, there are variables for easy, medium and hard.

By bumper, they are all alike and a good deal like the jolt ram.

Drawing pattern, finishing and blacking time allowances are obtained by getting the square inches of the area of pattern (including core prints and loose pieces) which are multiplied by a set variable for each square inch. There are four classes of finish, namely, very easy, easy, medium, and hard. There is a special variable for drying wet blacking, also for drying and baking flour facing molds with torch or charcoal fires.

As stated before, gaggers, spikes, nails, cores, etc., are taken care of by the general sheets covering all departments of the foundry.

As floor and crane work requires special features on certain jobs, we have a sheet called the "miscellaneous sheet." This takes care of such things as screw clamps—small, medium, and large; setting blocks and binders for one or two chaplets—small, large by hand, and large by crane; wedges; core supports; leveling mold or mold board; use of straight edge; rods or pipes for carrying off vents from cores; boxing of loose piece in green sand; making joint and using covering cores, and several others—easy, medium, and hard.

Pouring and dumping are taken care of by time allowances of their own in the different branches of the foundry.

All supplies such as nails, blacking, cores, etc., are brought to the floor or bench of the respective workmen.

All standards and variables included in the timing system are

built up from a large number of time studies taken in our own foundry. When a workman feels that the time allowed for a certain job after he has made it, is not correct, he notifies his foreman and he in turn takes the matter up with the time study man, who will check up on the job and, if necessary, go to the man's floor and take a time study of the job in question in the presence of the foreman of the respective department.

The Point System for Determining Molding Piece Rates

By W. J. MacNeill,* Milwaukee

Abstract

The point system consists of determining items involved in labor of making molds, assigning relative values to each and then setting rates for individual patterns according to the points involved. Examples of application to specific jobs are cited. It is stated that this system is best applicable to squeeze jobs and to bench molding, although floor jobs can in some cases be adapted to the system. This method is of value to salesmen in estimating molding costs quickly.

1. The point system for determining molding piece rates in use at the Federal Malleable Co. was, to the best of our knowledge, developed through the cooperation of members of the American Malleable Castings Association, now known as the Malleable Iron Research Institute, somewhat more than ten years ago. This method has been used in our plant since 1922 with only very slight alterations, and we have found it most satisfactory for rating squeezer and bench molding jobs.

2. The application of the point system consists of assigning values to each part of the mold-making operation, these values being expressed in points. The sum of the points represents the total value of the various operations required for making the mold, but does not express this value as a price per mold. To convert the total points into a price per 100 molds, this total must be multiplied by an hourly earning coefficient. To this product is added the pouring, which, in our shop, is paid for at the rate of 10 cents per cwt. of casting weight per 100 molds.

*Superintendent, Federal Malleable Co.

Note: This paper was presented and discussed before the cost session at the 1931 convention of the American Foundrymen's Association.

Basis of Point System

3. The basis of the point system under discussion here is given in the tabulation of point values and hourly earning coefficients of Table 1.

Examples of System's Application

4. The examples of Tables 2 and 3 illustrate the application of the point system to specific jobs.

5. From the above examples it will be noted that, for convenience in converting total points into dollars per 100 molds, points should be considered as cents so that the multiplication by the coefficient gives a direct answer in dollars and cents and no confusion results in pointing off the proper number of decimal places.

Table 1

POINT VALUES AND HOURLY EARNING COEFFICIENTS

Operation.	Points
Sand Handling	30 for each 1000 cu. in. of flask content 50 for each 1000 cu. in. of flask content above 2000
Chills	1 for each chill which can be dropped in place 2 for each chill which must be set carefully
Bands	2 for each band placed in mold
Core Setting	1 for each small core dropped into place 2 for each small core set into place 3 for each medium core set into place 4 for each large core set into place 6 for each small complex core set into place 8 for each large complex core set into place
Handling Equipment	12 for each plate pattern of 1 gate for squeezer 2 for each additional gate 14 for each frame pattern of 1 gate for squeezer 2 for each additional duplicate gate 17 for each hand pattern for squeezer 4 for each additional duplicate of gate 6 for each additional different gate 17 for each plate pattern hand rammed 20 for each hand pattern hand rammed 4 for each additional duplicate gate 6 for each additional different gate

Hourly earning desired	50c	55c	60c	70c	75c	80c	90c	1.00	1.10
Coefficient	5	5½	6	7	7½	8	9	10	11

Pouring: 10c per cwt. of casting weight per 100 molds.

Table 2

EXAMPLE OF APPLICATION OF POINT SYSTEM IN FOUNDRY

Casting weight, ½ lb.; pieces per mold, 10; cores, none; flask size, 10 × 16 × 7. Equipment, plate. Made on squeezer.

Sand (10 × 16 × 7) = 1120 cu. in. @ 30 pts. per M cu. in. (33.6)	.34
Cores and chills—none	
Pattern equipment—plate on squeezer	.12
Total points	.46
Hourly rate desired, 70c	×7
	3.22
Casting weight per mold, 5.0 lbs.—per 100 molds, 500 lbs., @ 10c per cwt.	.50
Total piece rate per 100 molds	$3.72

Table 3

EXAMPLE OF APPLICATION OF POINT SYSTEM IN FOUNDRY

Casting weight 6.00 lbs.; pieces per mold, 2; weight per mold, 12 lbs.; flask size, 12×20×10; cores per piece, 1 large, 1 medium. Equipment, hand pattern. Molding method, hand rammed.

Sand (12×20×10)=2400 cu. in—2000 cu. in. @ 30 per M	.60
400 cu. in. @ 50 per M	.20
Cores—2 large @ 4, 2 medium @ 3	.14
Equipment—1 hand pattern, hand rammed	.20
Total points	1.14
Hourly rate desired, 80c	×8
	9.12
Pouring—12 lbs. per mold, 1200 lbs. per 100 molds, @ 10c per cwt.	1.20
Total piece rate per 100 molds	$10.32

Jobs Where System Is Applicable

6. The point system as outlined can be applied to practically any squeezer job and to about 80 per cent of the bench jobs. We have found that it is not reliable for very complicated bench work, nor for any floor or large machine jobs on direct application. However, it is possible to make an application indirectly, as follows:

7. Take a job on which a satisfactory molding price has been established and determine the total points. Divide the price by the total points to get the value of the point in cents. Determine the total points for the new floor or bench job in the usual manner and multiply the total points by the value per point to establish the new molding price.

8. For example, suppose we are required to set a price on a floor job weighing 20 lbs. having no core in a 20 x 40 x 8 inch flask. The ordinary application of the point system gives $23.00 per 100 molds as the piece rate. Knowing that this rate is entirely too high, we check into other floor jobs which we have made before and find a somewhat similar job which has been running very satisfactorily at a piece rate of $17.25 per 100 molds. We find that the total for this job is 400 points, or a value per point of $.0431. The points for the new job total 300, so the total price is 300 $\times$ $.0431, or $12.93 per 100 molds.

9. We have found that the value per point varies widely between floor and bench jobs, but by selecting the standards of point value from jobs which have been well established, practically any job can be rated under the point system.

Aids Rapid Estimate of Molding Costs

10. In addition to establishing a definite standard for molding rates in the foundry, the point system can be used to great advantage by the sales department for estimating purposes. Any salesman who understands the rudiments of molding can estimate the flask size and rate the cores in a job closely enough to permit him to make an estimate of the molding cost of a job which will be very close to the price actually paid.

11. Thus, he is enabled to make a casting price to the customer in many cases where, without the aid of the point system,

he would be obliged to go back to the plant and confer with the foundry foreman before being able to quote on the job.

12. Some of the standards of the point system have been criticized by people who have checked them against time studies. To our knowledge, the principal complaint made is against the allowances for setting or dropping a large number of small cores. It seems that when more than eight similar cores are set or dropped in one mold, the allowances of two and one points, respectively, are too high, and allowances of 1½ and ½ points are ample.

13. The rest of the system seems to check very closely with time-study rates. Since the majority of foundries have no time-study facilities, the point system offers to them a simple, reliable method of establishing equitable molding piece rates.

Scientific Rate Setting in Foundries

By T. M. HARRISON,* CLEVELAND

Abstract

Scientific rate setting on molding and core-making operations is very important as a means of reducing and controlling direct labor costs, as a basis for standard cost finding and as a basis for exact estimating. The method advocated is to establish the time of various fundamental operations and then to determine those which go to make up the elements of any particular job. An example is given. Day work versus wage incentive systems is discussed.

1. The writer is in an excellent position to understand the needs of foundrymen, especially from the standpoint of executive control. He believes that the executives of your industry are overlooking a vital thing when they fail to appreciate the importance of *scientific rate-setting.* At first glance, rate setting may seem to be "just another system;" however, the lack of it lies at the heart of many a foundryman's troubles.

2. The purpose of this brief paper, then, is to emphasize the importance of scientific rate setting to cover molding and core making. It is sought to make its importance clear from three points of view, as follows:

(a) As a means of reducing and controlling direct labor cost.

(b) As a basis for *standard* cost finding.

(c) As a basis for *exact* estimating.

3. Basic data as to the time required to perform these operations is fundamental. It has a two-fold or three-fold purpose—it not only makes possible a high degree of labor control, but also

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NOTE: This paper was presented and discussed before the cost session at the 1931 convention of the American Foundrymen's Association.

underlies statistical information of the greatest importance from the standpoint of general control.

Wage Payment Systems

4. To begin with, it may be wise to consider the present condition of the industry with regard to wage incentives and the kind of incentives in use. A large percentage of gray iron foundries, more especially the smaller jobbing foundries, use the day-work method of payment. Some of the larger jobbing gray iron foundries and a good many steel foundries use piecework, but unfortunately piece rates in most cases are set merely in accordance with the judgment of the superintendent, foreman or rate setter.

5. Certainly, piecework insures lower labor costs than day work, even when the rates are set merely by judgment. Nevertheless, piece prices ordinarily may be considerably reduced by the use of scientific rate setting. Consequently, the system outlined is recommended not merely for foundries now on day work, but also as a substitute for rate setting by judgment in piecework foundries.

Elementary Time Studies

6. Scientific rate setting involves the use of stop-watch studies, and it should be pointed out that there are two distinct kinds of time studies—one made with reference to the individual pattern or core box, the other with reference to individual *elements* of the work.

7. In all jobbing foundries, and in many foundries making a standard line of product, time studying by individual patterns would be a tremendous and more or less continuous task. Consequently, we deal herein with the second method; that is, with time-studies to cover elementary operations rather than specific patterns.

8. From the standpoint of this type of time study, molding and core making are not merely operations. Each represents a combination of a large number of elementary operations.

9. It has been proved beyond question that in the case of each one of these elementary operations there is a unit that will properly measure the distinction in labor difficulty between one pattern or core box and another. In molding, for instance, there are certain flask-handling, sand-handling, core and supply handling, finishing and other elements. Thus, it is only necessary to establish

basic rates, expressed in the proper units of measure, in order to make it possible to build up synthetically an over-all time allowance to cover the making of a mold from any pattern in any flask.

10. Foundrymen who are familiar with this method of rate-setting will admit its effectiveness at once, but for the benefit of those to whom it is not familiar, it will be wise to illustrate the plan further. In Table 1 are listed numerous elements of floor molding, grouped in accordance with the units by which they are measured.

11. Under this system there are two distinct steps. The first is to make time-studies and build charts or tables covering all elementary time allowances. This is a task that is rapidly completed once and for all. The second step has to do with establishing time allowances for individual patterns and core boxes from the basic data. It will be wise to deal with each of these steps individually.

Table 1

ELEMENTS IN FLOOR MOLDING

Level floor	Roll over
Place bottom board	Remove clamp and board
Place drag	Make joint
Strike off	Place cope
Place board	Remove cope
Clamp	Close mold

Unit of measure: Area of top of flask (by class of joint).

Place pattern. *Unit of measure: Per piece (by class).*

Shovel and ram. *Unit of measure: Cubic inches of sand (by class).*

Set gaggers. *Unit of measure: Per piece.*

Draw pattern
Finish
Blacken

Unit of measure: Area of pattern (by class).

Set cores. *Unit of measure: Per piece (by class).*

Final clamping. *Unit of measure: Per clamp (by class).*

Other elements include miscellaneous items to cover the following: Bolt and unbolt bottom plate; fasten pattern to cope; dry wet blackening; build runner box; rap pattern through cope; draw pattern pins; set nails; place wedges between cope bar and core print; carry off vent with rod, clay and cinders, etc.

Elementary Time Allowances

12. In some cases these elements or groups of elements are measured by a single unit of time which is multiplied by the factor representing size, volume, or pieces. In other cases the unit changes with the size, volume or pieces and the basic data may best be presented in the form of charts or tables.

13. As an instance of this, take the first group, which we will call "flask handling" elements. In this case the allowance per hundred square inches of flask area varies with the size of the flask and therefore may best be presented in chart form.

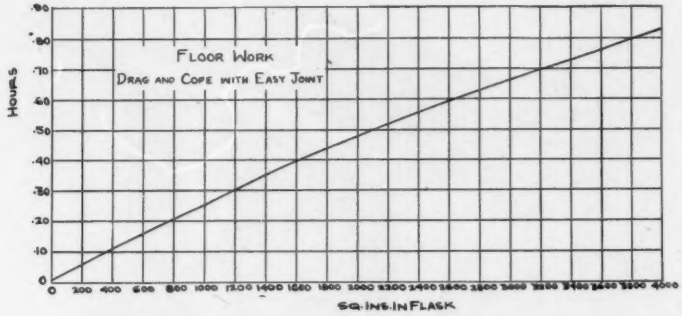

FIG. 1—TIME ALLOWANCES FOR "FLASK HANDLING" ELEMENTS.

There are three charts which reflect the varying amount of labor difficulty in making the joint. Fig. 1 gives time allowances for various sizes of flask with medium joint.

14. While there is a good deal of similarity between the time allowances as established in different foundries of the same type, it is necessary to make time studies locally in order to be sure that the standard times reflect the local conditions, equipment and methods. The time required to make such studies varies, of course, with the range of the work; but whatever time is required, it is well spent because of the permanent, basic and vital nature of the information developed.

15. If the reader will assume, then, that basic time allowances have been established covering all elements and that charts and tables have been provided to make the data readily available

to the rate setter, we will go forward to show how the information is used.

Rate Setting

16. In order to illustrate the rate-setting feature, we present a sketch of an imaginary casting (Fig. 2) and for illustrative purposes throw together the various elements involved in making the mold from the pattern such a casting would require. In this connection we use a specification sheet (see Fig. 3).

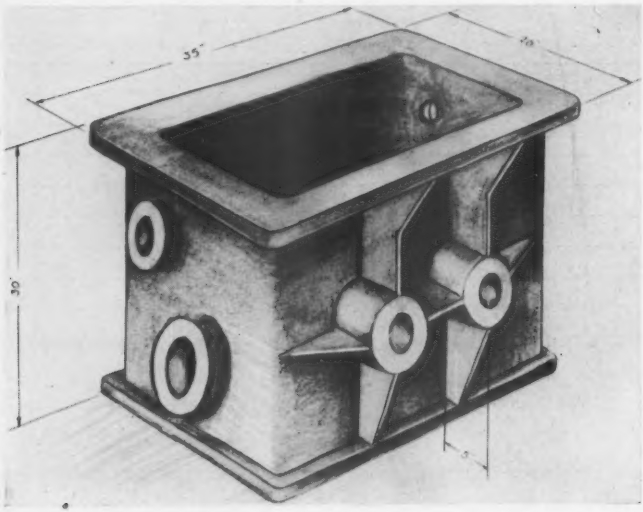

FIG. 2—SKETCH OF CASTING (PATTERN NO. 26-432).

17. The first step is to determine the square inches of area in the top of the flask and the approximate square inches and cubic inches in the pattern, from which may be determined the cubic inches of sand. Whether the wage incentive system used is piecework or bonus, the original computation must be made in hours. In Fig. 3, then, the allowances for individual elements, or groups of elements, and for the molding as a whole, will be found stated in hours.

18. In jobbing foundries rate setting is a continuous task, and in any foundry it is a task that must be done every time a

pattern goes into the sand for the first time. To calculate the time allowances on specific patterns requires that the patterns must be measured and certain computations made. This takes a varying amount of effort according to the type of work.

19. The compilation for a molding machine pattern may be made in three or four minutes. On the ordinary run of side floor jobs the time per pattern may be six or eight minutes, and on center floor jobs, a longer time if the pattern is large and intricate. On miscellaneous work, then, a rate setter may readily cover sixty or seventy patterns a day, and since the time allowances on these patterns need be computed only once, it will be seen that rate setting in a foundry of average size is likely to be a part-time job.

20. For the benefit of those who are still using day work, it should be said that wage incentives are especially effective on

FLOOR MOLDING SPECIFICATION SHEET

FLASK 1440 SQ.IN. 576 CU.IN. PATTERN NO. 26-432
PATTERN 1155 SQ.IN. 8467.5 CU.IN. FLASK SIZE 36 X 40 COPE 20 DRAG 20
NET 3292.5 CU.IN. DATE

		QUAN.	RATE	HOURS
Flask handling and joint	Class ABC	1440		36
Place pattern by hand		4	.0075	.03
Place pattern by crane				
Bolt and unbolt bottom plate		8	.0200	.16
Face pattern, shovel and hand ram	Class AB			
Face pattern, shovel and air ram		329.25	.0015	.49
Face pattern, shovel and bump				
Face pattern, and sandslinger	Class ABC			
Draw pattern, finish and blacken	Class ABCD	57.75	.0200	1.03
Dry wet blackening with torch				
Build runner box	Class ABC			
Rap pattern through cope				
Draw pattern pins				
Set gaggers, soldiers or rods		65		.16
Set nails				
Set cores		1	.0500	.05
Set cores		4	.0035	.01
Set cores				
Final clamping		4	.0250	.10
TOTAL TIME				2.09

FIG. 3—SPECIFICATION SHEET (EXTENDED FOR PATTERN NO. 26-432).

such largely manual operations as molding and core making. The pace of day workers in these operations is ordinarily very slow as compared with the pace that may be obtained under any effective wage incentive plan. Piecework or bonus very frequently will double the output per man hour with a large percentage reduction in direct labor costs.

Method Distinctly Applicable to Jobbing Foundries

21. Jobbing foundrymen especially will be likely to suppose that a system of this nature does not apply to the short runs inherent in jobbing work. This is a mistake—once the elementary times have been established, the rate-setting problem becomes so easy that jobbing foundries have no longer any excuse for operating on a day-work basis.

22. The difference between piecework and bonus is not understood or appreciated by the average foundry executive. If the foundryman cannot picture piecework in his plant, he is likely to arrive at the wholly erroneous conclusion that no wage incentive system is possible.

23. The fact is, that bonus is so much more elastic than piecework that it may be made to work effectively under almost any condition. The short runs and other difficulties encountered in jobbing foundries may be covered effectively by a properly designed bonus system even where piecework might not be so readily applicable.

24. For those who use piecework with rates set by judgment, it should be pointed out that where judgment is exercised the benefit of the doubt ordinarily is reflected in the piece rate, and that really minimized rates can only be arrived at where all elements are properly measured. In rate setting by judgment, there is no assurance that two rate setters will get the same results, or even that a given rate setter will get the same result at different times. Scientific basic data, on the contrary, leads to rates that are not only uniformly equitable but ordinarily are lower, on the average, than can be hoped for under "rule-of-thumb" methods.

Day Work Versus Wage Incentives

25. We do not seek to advocate in this paper any particular form of wage incentive system. Whether piecework or bonus is

used, the fundamental data described is equally necessary and effective. Day work is a luxury few foundries can afford. A good wage incentive system should reduce the labor cost in the average day-work foundry by about twenty-five per cent.

26. It is, of course, difficult to generalize as to the value of scientific rate setting over rate setting by judgment in foundries now on piecework, because the saving will vary in accordance with the accuracy of the merely estimated rates. Ordinarily, however, scientific rate setting will save money, to say nothing of the value of relying for labor control on fixed fundamental data rather than wholly on the judgment of individuals, however well qualified they may be.

27. While the most obvious use of this fundamental data is in connection with wage incentives, suppose we devote a few paragraphs to the uses that may be made of it in other directions.

The Cost Finding Problem

28. Foundrymen will admit that there is a woeful lack of cost knowledge in the industry, and that certain of its outstanding troubles may be traced to that fact. What foundrymen have to fear is not merely competition so much as it is the unintelligent competition of the member who does not know his costs. Any system that aids in the determination of costs, therefore, must be regarded as important.

29. Before discussing the cost finding problem, it may be wise to briefly deal with, and to eliminate from further consideration, the question of overheads. Much educational work has been done by various associations and groups to insure that overheads are calculated and allocated in a reasonable manner—some items on a tonnage basis and some in accordance with direct labor costs. The industry is probably abreast of the times insofar as this element is concerned. At any rate, no attempt can be made to deal with the question here.

30. Let us see where the chief difficulty in cost finding lies. It certainly is not in establishing the cost of the metal, for most foundrymen know the cost of metal at the spout. A large proportion of foundrymen, too, have an analysis of overhead detailed enough to enable them to apply that element of cost with reasonable accuracy.

31. The greatest difficulty arises, then, in the determination of the direct labor cost of each casting. In many foundries detailed time records are made by floating time keepers, but even in such cases the allocation of time, especially on small work, is liable to be more or less arbitrary.

Standard Cost Finding

32. Please note this important fact: Elementary time allowances provide a means of *predetermining* direct labor costs and, therefore, total costs by individual castings. In other words, they make possible a *standard* cost system.

33. This paper is of necessity too short to deal with the principles of standardized cost finding, but foundry accountants who are familiar with recent developments will know that under this system all individual castings costs are predetermined, and variations from standard are drawn off in weekly and monthly periods merely by classes of expenditure.

34. Under standard costs, the actual cost of operating for the month is accounted for under two heads: First, the standard value of the product, and second, the variations from standard. The variations from standard are handled as follows: (1) Metal at the spout—variations from standard price per hundred, drawn off once a month; (2) direct labor—variations from standard time allowances drawn off by pay periods, by departments; (3) overhead expenses—variations from standard percentages and tonnage units, drawn off each month. The variations are treated not as charges to individual castings but rather as items of operating profit or loss.

35. Standard costs have certain definite advantages in a foundry. First, they are more accurate than figures built up through day-to-day time keeping. Second, the clerical labor involved in maintaining the system is much lower than it is under order costs. Third, the costs are known before the castings are produced.

Estimating

36. In jobbing foundries, estimating is an outstanding problem. It has all the difficulties of the cost finding problem, together with the added difficulty that the estimate must be made before the goods are produced. As in the case of the cost finding prob-

lem, the greatest difficulty presented is in determining the time required to perform the direct labor operations.

37. However, if the estimator is working from exactly the same basic data as the rate setter, it is a foregone conclusion that the estimated labor costs will agree with the rates established in the plant. Again, if the estimator is using the same cost per pound for metal, and percentages and tonnage rates for overhead, it is apparent that the other elements in the computation will conform with those compiled by the cost department, provided the cost department uses standardized rates.

38. Briefly, then, the estimate should agree with the actual cost if order costs are used. If standard costs are used, the estimate becomes the standard cost and no further calculations are made, so far as individual castings are concerned.

39. There is surely no need for argument as to the necessity for accuracy in estimating, and no further need to point out the fact that the fundamental data established primarily for use in rate setting is exactly that data which will insure accurate estimating.

SUMMARY

40. What we have sought to establish, then, is, first of all, the vital importance of minimizing and controlling direct labor costs by the use of fundamental data established through elementary time studies. In day-work foundries this should be used as the basis for wage incentive systems, and in piecework foundries, as a means of equalizing and reducing unscientific rates—thus placing the reliance for labor control on scientific data as against mere judgment.

41. The second suggested use of the fundamental data, that in connection with standard cost finding, is undoubtedly of less importance. However, in many cases standard costs will minimize clerical effort and at the same time increase the accuracy and the value of cost information.

42. In jobbing foundries it is impossible to over-emphasize the necessity for accurate estimating. This type of fundamental data makes *exact* estimating possible. Is it not apparent that in such foundries reduced labor costs and exact estimating form a vital combination?

43. Considering the matter broadly, then, are we not justified when we say that scientific rate setting, viewed from the standpoint of labor control and also in the light of its statistical value, is a matter of prime importance in foundry operations?

A Contribution to the Studies of Methods for the Control of Foundry Products*

By Pierre Nicolau,† Paris, France

Introduction

1. Under the auspices of the International Committee for Methods of Testing Cast Irons, and also of its learned president, Mr. Portevin, the study of procedure in determining the quality of foundry products, which had been neglected for a long time, has more recently been the object of some very remarkable work in all industrial countries. The reports presented at recent technical society meetings by the most competent authorities on cast products, and also the discussions which followed, indicate the interest taken now by the foundrymen in the search for the best methods to determine the essential properties of castings, as well as for methods to reveal their possible defects.

2. Knowing that, since the end of the last century, the progress in metallurgy has been due to the ever better methods of testing materials, the foundrymen and their customers have been convinced that the destinies of their art are intimately connected with the scientific determination and the exact numerical valuation of the properties of the cast iron products.

3. It is not our purpose to give here a complete description of the methods for the control of foundry products. In the periodical exchange of papers between our French Technical Association of foundrymen and the American Foundrymen's Association, it is our object to supply the engineers of both countries with data concerning their special and respective work.

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* Presented as the official exchange paper of the Association Technique de Fonderie de France, the French Technical Foundry Association.

† Major, Technical Section, French Artillery.

Note: This paper was presented and discussed before one of the gray iron sessions at the 1931 convention of the American Foundrymen's Association.

4. I shall try herein to sum up for the benefit of our colleagues and friends in America the contributions brought forth by France, and I shall present a description of our methods with their improvements. My presentation will reflect, of course, the present tendency of the French commission on methods for testing cast iron,* work in which I was asked to take an active part, as well as of studies made in France since the fundamental researches by Fremont, Portevin, Ronceray and LeThomas.†

5. Because it is important that everyone contribute some material to build up the common knowledge in the pursuit of progressive knowledge, I shall advance the ideas which today are generally accepted by competent men in France, as well as some experimental results which I have been able to gather from tests I have made, also some new suggestions which I thought could be derived from those tests.

6. In principle, I shall consider only gray iron castings, but my conclusions can be applied to all foundry products, of which the two essential characteristics are (1) non-uniformity and (2) poor resistance to deformation.

7. I shall first mention the testing methods used until recently in France and criticize them. Then, after explaining the conditions we must obtain which will permit us to evaluate each casting in a judicious manner, I shall survey the methods which, at the present stage of our knowledge, can be substituted for the old methods, and review the conditions of their application, taking special notice of those methods which are capable of being utilized as acceptance tests of the finished castings.

I—THE OLD METHODS

8. In all probability, artillerymen were the first to realize the necessity of controlling the practical value of foundry products since the time when, for the sake of economy, cannon formerly cast in bronze (the Eighteenth century) were cast in cast iron.

9. Originally, there was no test on specimens separately cast. After the guns were made, they were tested by firing them with an amount of gunpowder in excess of what we call the max-

*Commission Institute por l' Association Technique de Fonderie.
†See Bibliography appearing at the end of this paper.

imum permissible load. After firing, the inside surface of the gun was inspected in order to discover any possible fault in the casting.

10. Such inspection was done by using a certain instrument made up of a number of elastic blades with their ends shaped like hooks. Such an instrument was called a "cat," but the foundrymen, frightened by the investigations resulting from the information obtained by that instrument, used to call it "the devil" (Fig. 1).

11. In other words, at that time the products of the foundry which were so important to the artillerymen, especially in regard to safety, had to be gaged as to the following two essential points:

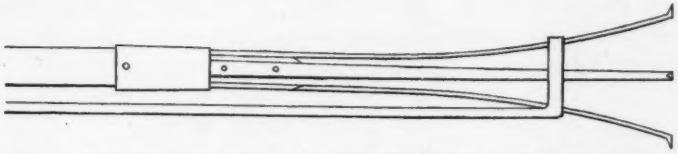

FIG. 1—HANDLED TOOL, CALLED A "CAT," FOR EXAMINATION OF THE INSIDE OF GUNS.

(a) To control the value of the finished product (by firing test with excess powder charge).

(b) To find out the local defects (by inside exploration of the surface with the instrument called the "cat").

12. These two points have been lost sight of by the new methods of testing cast iron products.

13. Unfortunately, testing the guns by firing with an excess powder charge produced excessive stresses in the metal, often resulting in cracks appearing on the inside edges of the guns. Although guns thus overstressed apparently held up when tested, they still were vitally affected and the consequence was that after a more or less normal length of service the guns developed splints or burst. We distinctly know today that the process of such cracks, being progressive under repeated fire, surely lead

to rupture, even during their use,[35*] so that in the end such firing test had to be abandoned.

14. De Montalembert very wisely suggested for the testing of cast iron a different method, called the density test, by weighing each gun once in the air and once in the water. Such a method enabled the tester to eliminate the guns defective because of blowholes, or those made of some light or porous cast iron.[1] It was only at the end of the Eighteenth century that, under the proposition of Monge,[2] the artillerymen decided to make mechanical tests of cast-iron guns on special specimens separately cast.

15. In spite of abandonment of the manufacture of cast-iron guns, tests on cast iron have been made by static flexure, as initiated by Monge. These tests have been continued up to our present day, although other tests have been added (unsuitable, as we shall see) by testing cast iron in tension, instead of by static flexure as before. More recently, in France, cast irons have been tested on specimens separately cast, submitting them to the following stresses:

(a) Static flexure.
(b) Flexure by shock.
(c) Slow tension.
(d) Compression.

16. I shall mention briefly how these different tests were carried out.

Test of Static Flexure

17. This test was made by using the Monge instrument (Fig. 2). Although invented by Ramus[3] in the year 1790, this instrument took the name of the great scientist Monge, who in the year 1794 advocated its use for testing cast iron in the manufacture of guns (Fig. 2).

18. In its primitive form, which has been continued to this day, this instrument consists of a cast-iron box *A-A*, sealed in a solid wall in which the specimen to be tested is supported by a knife (*a*). At the end of the specimen a lever is fixed, bearing, at a certain distance from the point *a*, a scale with a loading platform. When the specimen is loaded, it bears on a second knife (*b*). Loads are placed on the scale gradually until rup-

*Reference numbers correspond with those of articles listed in Bibliography at the end of this paper.

ture of the specimen. Specimens are rectangular bars whose cross-section is 40 or 80 mm. (1.57 in. or 3.14 in.) square, according to the type adopted.

19. The total length is 450 mm. (17.8 in.) The distance between the knives is 150 mm. (5.9 in.), and the distance from the point of application of the loads to the knife (*b*) is 2 meters (6.56 ft.) for bars of 80 mm. (3.14 in.), and 1.50 meters (4.92 ft.) for bars of 40 mm. (1.57 in.) The quality of the specimens is shown by the load applied in *f*, which causes their rupture, taking into account the dead load of the lever itself with the scale.

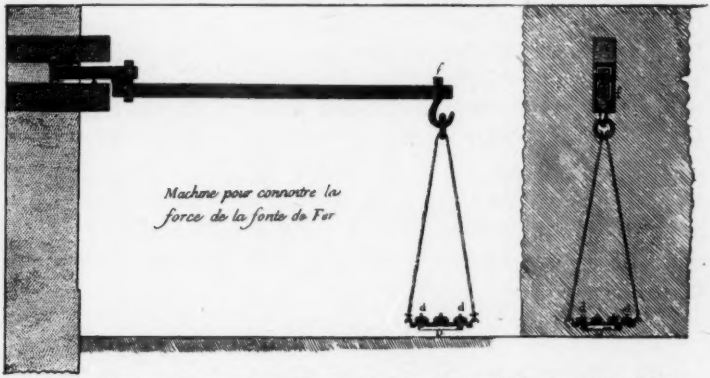

FIG. 2—MONGE APPARATUS INVENTED BY RAMUS IN 1796 FOR THE STATIC FLEXURE OF CAST IRONS.

20. However, it is to be noted that, about the year 1860, the National Navy substituted the Monge static flexure test on bars 50 × 50 × 500 mm. (1.97 × 1.97 × 19.7 in.), using a Joessel scale, which at that time was considered a very remarkable instrument. For a considerable time it was used by the artillery to calibrate the pressure test cylinders.

Test of Flexure by Shock

21. This kind of test was made by an instrument consisting of a hammer with an anvil. (In a way it was like the standard drop-testing machine of the American Railways Engineering Association.) The weight of the anvil is 800 kg. (1764 lbs.), supported

on a block of masonry. The specimen bars to be tested have a section 40 mm. square and 200 mm. long (1.57 in. square, 7.87 in. long).

22. The bars are placed on two steel knives, spaced 16 cm. (6.30 in.) center to center. The weight of the hammer is 12 kg. (26.46 lbs.), falling exactly on the middle of the bar. This test consists in submitting the bar to repeated falls of the hammer and each time increasing the height of the fall by a certain increment, starting from a certain established height. For each quality of cast iron the initial height is fixed, as well as the increments of each fall and the minimum fall which the bar should resist.

23. Although flexure tests by shock are comparatively more recent than the Monge static flexure tests, for a long time the foundrymen of all countries have been engaged in trying to find a proper method of testing their own products by shock. Fremont reported that the work of Thomas Tredgold in 1826 attracted attention to the ability of cast iron to resist impact.

24. In France, by decree of the Ministry dated Feb. 29, 1836, certain gun-brackets in cast iron had to be tested under specified conditions to the shock of a hammer. Even today, certain specifications require that shock tests are to be made on finished parts.

Tension Tests

25. Determining the qualities of metallurgical products by tension tests is an old method. In France it can be traced to the Eighteenth century. Naturally, it has been developed in this period of evolution in the testing of materials, which period can be called "the tension age." In spite of the interest of certain manufacturers of tension instruments, such a period now approaches its end. Recently, however, in France, tension tests have been made on rough cylindrical specimens taken from the interior of the casting and shaped to a section having an area of 500 sq. mm. (19.7 sq. in.).

Compression Tests

26. The compression test seems to have appeared in specifications toward the end of the Nineteenth century. It is still made, generally, on cylindrical specimens with a section of 16 mm. (0.63 in.) diameter and 16 mm. (0.63 in.) long.

II—CRITICAL EXAMINATION OF THE ANCIENT METHODS

Tension Method

27. At first such a testing method appears illogical. Knowing that cast iron is not a fit material to resist tension stresses, such a test has no logical reason to be used, especially since tension stresses are always accompanied by parasitic flexions causing rupture.

28. In fact, in the ordinary practice in testing it is impossible to determine the exact resistance to tension of cast iron, because it is almost impossible to set the bearings in the axis of the specimen. As a rule, such specimens break prematurely by

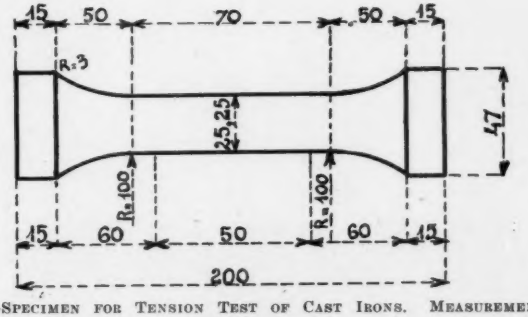

FIG. 3—SPECIMEN FOR TENSION TEST OF CAST IRONS. MEASUREMENTS IN MILLIMETERS.

flexure in the holders. The maximum stress measured is always below its real value.

29. The less perfect the machine, the greater the error; and, as pointed out by Fremont,[3] the error is still greater when cast iron is of high strength. It is a known fact that, whatever the amount of care taken in operating the testing machine, the specimen, although apparently submitted only to tension, unsuspectingly undergoes also some flexure strain, which means additional tension.

30. It appears that the stronger the cast iron is, the less it is fit to receive elastic or permanent deformation, for the simple reason that a material with a lesser deformation is less ductile, although otherwise it is a stronger and better material.

31. The use of specimens, such as that of Fig. 3 which has been designed to localize the section of rupture in the middle portion, is not sufficient to eliminate this important cause of error.

32. For my part I do not believe I have ever succeeded in performing correctly this test of cast irons (even on machine-finished specimens), in spite of using for such tests a testing machine having a good reputation; in spite, also, of careful precautions which, in industrial practice, have been judged as prohibitive. In my opinion the tension tests of cast iron should be abandoned as unreasonable and practically incorrect.

Flexure Test by Shock

33. Such tests as these no doubt have been started with the object of determining the brittleness of cast iron. However, one fails to see any interest in determining the brittleness of metallurgical products which, like cast iron, are by nature essentially brittle, since for this very reason they must be carefully preserved from being stressed by shock.

34. Since 1909, Fremont[3] has concluded that this test is in-

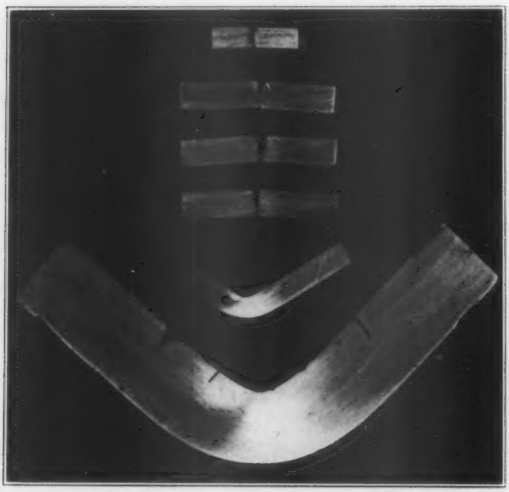

FIG. 4—RESULTS OF TESTS ON BRITTLE STEEL, BY SHOCK AND BY BENDING, ON UN-NOTCHED BARS, AS COMPARED WITH TESTS BY FLEXURE ON NOTCHED BARS. UPPER TWO SPECIMENS ARE THE UN-NOTCHED BARS.

expedient, pointing out that, the rupture of cast iron occurring always between the grains, the breakage is always full-grained, either by using the "static" mechanical method or the "dynamic" one. Consequently, the test by shock is not advisable because cast iron has only one form of rupture.

35. In fact, as a general rule, the flexure test by shock on specimen bars, un-notched, does not give any information about the brittleness of a metallurgical product. Especially is this so because our industrial testing machines permit only of a slow speed, and this method of testing shares in the phenomenon of static flexure. The available energy of the hammer is not for the main part utilized to break the test specimen, but to cause deformation before rupture.

36. The fact is, then, that the metals which offer the greatest capacity of deformation are those which, tested by shock, give the best results, and inversely. Of these facts I have given an experimental demonstration which is particularly striking, as shown in Fig. 4.

37. The example shown is of an axle broken while in use, which by mistake was made of manganese-silicon steel, self-hardened and with too high sulphur and phosphorus. Tested to flexure by shock, as it is done, in similar conditions for cast iron [fall, 2 m. and 75 cm. (108 in.); hammer, 18 kg. (39.69 lbs.); specimen bars, $30 \times 30 \times 200$ mm. ($1.18 \times 1.18 \times 7.87$ in.), on supports spacing 16 cm. (6.30 in.)], the steel offers a remarkable resistance; it is impossible to break it. In the same manner, a specimen bar of $70 \times 24 \times 9$ mm. ($2.75 \times 0.94 \times 0.35$ in.), held at one end over one-third of its length, in a rotating vice, cannot be broken by the repeated fall of a hammer weighing 10 kg. (22.05 lbs.) with a fall of 50 cm. (19.7 in.)

38. In the upper part of Fig. 4 are shown the two specimens, submitted to flexure by shock and to bending by shock, unbroken after having been submitted to the maximum possible deformation as permitted by the experimental arrangement. Beneath the first two specimens in Fig. 4 are four other specimens, tested to flexure by shock on notched bars (Charpy, Mesnager, W. F., and Fremont types) taken from the same sample of steel.

39. These four bars broke without previous noticeable deformation, and for all of them the energy absorbed by the rup-

ture has been extremely small. Consequently, it is well established that, in principle, the test by shock on un-notched bars does not reveal any structural brittleness. It does not appear that it is possible, in the present stage of our knowledge, to make an exact mathematical analysis of the shock of a hammer on a specimen of cast iron.

40. If, however, in a first approximation we suppose that the permanent deformation of the specimen is negligible during the shock, and if we admit the effort (F) developed during the shock is proportional to the time, we can write the following equation when H equals the fall corresponding exactly to the rupture of the specimen:

$$V = \sqrt{2gH} \text{ and } mV = \int_o^T F\,dt, \text{ from which}$$

$$F_m = \frac{2mV}{T}$$

where m = Mass of the hammer.
V = Speed of hammer at moment of impact.
T = Duration of the shock.
g = Acceleration of the hammer.
F_m = Maximum effort endured by specimen during time T, under which it breaks.

41. Now the duration T of the elastic shock is $T = \frac{K}{u}$, in which K is a constant value depending on the dimensions and the masses of the specimen and of the hammer.

42. Besides, knowing that

$$u = \sqrt{\frac{g\,M}{d}}$$

in which M = modulus of elasticity of cast iron, and d = its specific weight, we finally find

$$F_m = \frac{2mV}{K}\sqrt{\frac{g\,M}{d}}$$

43. This expression shows that the maximum stress resisted by the specimen is proportional to the square root of the elastic modulus of cast iron.

44. With the alternative form of equation

$$\frac{H\,M}{d} = K_1\,F_m^2$$

we can also say that, in order to determine the rupture of the specimen, it is necessary, all things being equal, that the fall of the hammer be proportionately higher when the elastic modulus is lower. In other words, as we shall see later, the fall should be higher for cast iron of an inferior quality. In fact, the shock is not entirely elastic.

45. After the elastic period, or nearly so, of duration T, follows a period of permanent deformation of duration T', during which the law of variation of the energy as a function of the time is a characteristic of the testing of cast iron. This cannot be expressed in mathematical language. It is, however, understandable that, for the same value of T, (that is, for cast irons with the same modulus of elasticity), the larger the capacity of deformation, the greater the value of T'; or, in other words, the higher will be the fall causing rupture and the greater will be the resistance of the cast iron to shock.

46. Thus, we will say that the resistance to shock will increase when the modulus of elasticity decreases, as well as when the permanent deformation increases. In ordinary cast irons, these two circumstances occur simultaneously. That is why I have often found that cast irons of poor quality were more resistant to shocks, and inversely.

47. We should not generalize this conclusion, however, because it may happen that a given quality of cast iron with a high modulus of elasticity, such as good cast iron, might have a capacity of permanent deformation which would largely compensate its deficiency of elastic deformation This same good quality of cast iron will have a greater resistance to shock, as well as will a low quality cast iron.

48. By the way, these considerations are sufficient to explain why there is no relation, as Fremont[3] has shown, between the resistance to flexure by shock and the resistance to shear and, consequently, the resistance to tension. In fact, I have often noticed that the flexure test by shock did not afford any guaranty of quality in artillery firing of projectiles of cast iron (shrapnel shells and balls used in ballistic firing experiments). I have observed that specimens machined from projectiles of a type giving satisfaction in firing experiments, had a weak resistance to shocks.

49. *Vice versa,* the projectiles which were broken when falling

and hitting the ground, or otherwise resulting in the tearing off of the reinforcing rings, offered the highest resistance to shock. Determining the quality by the test of flexure by shock, we would have rejected the best balls and accepted the worst ones.

50. Data obtained on such foundry products as cast iron or steel shells have shown me that, out of 41 castings, 17 would have been rejected if we had taken into account the result of the tests by shock, in spite of the fact that these balls were satisfactory in firing experiments. One would be tempted to explain such discrepancies between the resistances to shock in field tests and in laboratory experiment, to a lack of accuracy or to some faulty arrangement of the old instruments used in these tests.

51. It was with such an attitude of mind that the Congress of foundrymen, which took place at Nancy in 1923, recommended the study of flexure testing by shock on specimens of $35 \times 10 \times 8$ mm. ($1.37 \times 0.39 \times 0.31$ in.), resting on two supports 30 mm. (1.18 in.) apart, the rupture resulting by only one shock, and the quality to be measured by the energy absorbed by the rupture.

52. I have made such tests on cast irons of balls made like the ones mentioned above, by using the smaller hammer-pendulum of 1 kg. (2.2 lbs.) of the Charpy type, built by Amsler. The preceding results have been confirmed even more clearly and definitely, the dispersion being less because of the greater perfection of the testing instrument. While the rupture of the specimens from balls giving satisfaction, requires in round figures 0.15 kg. (0.33 lbs.), it was necessary to have an energy of 0.20 kg. (0.44 lbs.) to break the specimens taken out from the defective balls.

53. As was established long ago, one thing of importance is the fact—confirmed by the above-mentioned experiments—that, in order to estimate the fitness of a foundry product to resist shocks, it is necessary to put a notch in the specimen intended for the flexure test by shock. It has been stated by Jean Durand[14] that flexure tests by shock on notched bars do not give the same classification of cast irons. This statement deserved some attention from the foundryman. In fact, it is possible that in the future a way will be found to make special cast iron products less brittle than the present ones when tested to flexure by shock on notched bars, and this test will furnish us the means of measuring this quality.

54. However, in the present state of our knowledge cast iron

products are essentially brittle and, besides offering differences in brittleness, are weak. All kinds of use made of cast irons show their brittle character. Consequently, it would be vain to try to figure this natural defect with any degree of exactness.

55. Summing up, it appears to be certain that it is best to give up the flexure test by shock, which is a very old method introduced in France without any justifiable reason. Because the test to flexure by shock on un-notched bars, as made in the industrial laboratories, is unable to evaluate the structural brittleness of cast irons, except their capacity of total deformation (elastic and permanent), which does not always offer a criterion of quality, it does not seem advisable to continue with this test until we get some more ample information on this testing method in our specification, even under some improved form—as, for instance, with a hammer-pendulum of the Charpy type of 1 kg. (2.2 lbs.) on the specimen bars $35 \times 10 \times 8$ mm. ($1.37 \times 0.39 \times 0.31$ in.) on supports spacing 30 mm. (1.18 in.). In any case, the conclusions which we formerly drew from this test as to the practical value of cast iron, are erroneous and most often reversed.

56. This state of affairs appears to be partly due to the fact that the capacity of elastic flexure is in general much higher in cast irons of an inferior quality, and partly because a greater capacity of permanent flexure is not necessarily an indication of good quality in cast iron.

Test by Elastic Flexure

57. This test, on the other hand, reflects the very conditions which normally cause the rupture of cast iron products while in use. This kind of test is, then, essentially logical. However, it is evident that the Monge instrument, for one reason, does not permit us to determine the resistance to flexure with a degree of exactness well in keeping with the actual progress of metallurgy and mechanics, and, for another reason, does not supply all the data needed concerning the quality of cast iron. The Monge testing machine belongs to a former age and it must be redesigned.

Compression Test

58. Compression tests are equally logical, because under normal conditions cast irons in application are almost always sub-

mitted to compression. However, the use of 16 mm. (0.63 in.) cylinders requires a powerful machine—20 tons (44,800 lbs.)—which means costly tools that are seldom available to foundrymen. On the other hand, because of their dimensions, these cylinders cannot be obtained in many instances from the castings.

III—CONDITIONS AND REQUIREMENTS OF METHODS FOR THE CONTROL OF THE FOUNDRY PRODUCTS

59. Two essential characteristics must regulate the choice of the testing methods:

(a) Heterogeneity.
(b) Small resistance to deformation.

Conditions Resulting from Heterogeneity

60. Cast irons are essentially heterogeneous. Aggregates of graphite, pearlite, cementite, or ferrite have very different mechanical characteristics. Their mechanical properties, in certain groups, are a complex function of the proportion and distribution of their elementary parts (without speaking of their secondary elements, such as impurities and local defects).

61. Now, if we set aside certain hereditary phenomena still not entirely definite, this variation is due not only to the chemical composition of the metal, especially of the elements such as Si, Mn, S and P, but also to their thermal history. This thermal history itself depends on the chemical composition (LeThomas[16, 18]) and in particular on the casting conditions, on the shape and thickness of the castings, and especially on the relative masses of the molds and castings.

Specimens Separately Cast

62. It is a fact that a test made on a specimen separately cast cannot give, with certainty, the information wanted regarding the mechanical value of castings of diversified forms and dimensions, although made with these same castings.

63. There is no doubt that the foundrymen are interested in evaluating cast iron without even regard to the various castings to be made therefrom. In the past, they have been led naturally to make tests on specimens of given forms and dimensions, under certain specified identical conditions.

64. Such was, no doubt, the origin of the tests on specimens separately cast. However, the buyer is not so much interested in the quality of cast iron, and consequently of the mechanical value of the typical specimens, as he is in the actual mechanical characteristics of the products of the same cast iron.

65. These characteristics not only concern the quality of the raw material, but also the conditions of casting. That is why only the tests on cast iron products in their actual shape and dimensions can satisfy him, because this test is their guaranty for good use in service.

66. For these reasons it is not possible to state as an absolute principle that we must not test cast irons on specimens separately cast. It is a matter of opinion. When a study of cast iron is wanted, without regard to its quality in the final castings, the use of specimens cast under some well-determined conditions is permissible. When it is desired to know the quality in the finished pieces, the employment of specimens taken from the finished products is the only admissible method.

67. I believe, however, that it is no exaggeration to say with Portevin[10] that it is unreasonable to extend the methods originally instituted by the foundrymen for evaluating raw material to that of acceptance tests for the finished castings.

The Small Specimens

68. Understanding that in order to evaluate the properties of castings it is necessary to submit such products to test, we may say that it is also conclusive that, as a general application, a testing method should be applicable to specimens made in their minimum possible volume or size. As there cannot be two different classes of methods for testing cast iron (one for raw materials and another for the finished products; one for the foundryman, the other for the user) and at the same time having it desirable, even if only for the sake of an expert valuation, to compare with certainty the results of tests made on castings with those made first on the general quality of the iron, we shall say that, as a general rule, tests of cast irons must be made on small specimens.

69. Another reason for accepting this rule is that small specimens are necessary in consideration of the fact that such castings are heterogeneous. In order to estimate the heterogeneity of a casting, and consequently find out the measure of its mechanical

value, we are necessarily led to multiply the number of tests in order to make in some manner a survey of its mechanical topography. By this method we assume that the volume (or the section) of each specimen is small enough to be unaffected by the heterogeneity resulting from the thermal history of the piece, and at the same time large enough to leave unnoticeable the effect of its heterogeneous crystallization. With Portevin[23] we shall say that "this volume should be statistically isothermal."

70. It is, for instance, without any interest to find out by tests made on a small ball under a small loading, the hardness of each of its elements: Graphite, pearlite, cementite or ferrite. The impression must, however, affect a number of crystallographic elements, such as to have each piece isothermal from the statistical point of view.

71. Portevin[23] reports that, according to Czochralski, a specimen of metal can be considered as almost isothermal if a transverse dimension consists of 10 grains. We can deduce the sizes of the smallest admissible dimensions for cast iron specimens. We can rely, for instance, on the fact that a test with a ball of 10 mm. (0.39 in.) under a loading of 3000 kg. (6615 lbs.) generally covers a volume of cast iron practically isothermal.

The Mechanical Topography of Foundry Products

72. I have said that the localization of the tests had, as a necessary corollary, the multiplication of their number, and we were led to examine the foundry products in order to make a survey of their mechanical properties. It is hardly necessary to add that, in order to get the best information, the examination must be made methodically.

73. I will state as a principle that if we want to get the best mechanical evaluation of castings, with the maximum of probabilities, the tests must be made on the doubtful portions.

74. All means capable of revealing such doubtful zones must be used. There are two kinds of doubtful zones, namely, those we know or foresee in relation to conditions of the casting in accordance with the general law of solidification, and those which escape our anticipations. In order to find and examine the first kind of zones, we must mark the specimens for test according to both main directions, the axis of the casting and the perpendicular to

the sides of specimens. Thus, in most cases we shall have to examine the top and bottom of each piece and also reach the interior of the thicker sections.

75. As to the defects which cannot be foreseen, we shall recommend for the time being a constant effort to locate these. We shall endeavor, later on, to show how such defects can be discovered without using the so-called "cat" invented by the artillerymen of the Eighteenth century.

76. In any case, we insist that a greater number of tests will give us more chances for revealing the weak points.

Interpretation of the Tests

77. When we increase the number of tests which are demanded by the heterogeneity of castings, we are bound to find a series of numerical results which, being all different, give us the picture of the heterogeneity of the piece. Because we failed in the beginning to emphasize the fact that the first object of testing materials is to discover the weak points of a piece, or the defective points of a number of pieces, we have brought confusion in many control operations.

78. The most unfavorable mechanical characteristics are the ones our specifications must carefully limit. We have wondered sometimes if, in our specifications, we had to base our acceptance of castings on an average value of the measured characteristics or on their minimum registered value. It is clear that if the method of the mechanical average value of a certain casting can be of use to the foundryman, it is not less indispensable for him to make sure that either an exaggerated zone of dispersion or some local defects of strength are not such as to cause him to disregard the value of the whole because of the existence of some less satisfactory points.

79. It is, then, a matter of importance to specify not only an average value but also a minimum value (or in some cases a maximum value) of the measured mechanical characteristics, this being a rather old rule of the French artillery. Summing up, in view of their reception and acceptance, the heterogeneity of foundry products has the following results:

(a) The acceptance tests must not be made on specimens which have been separately cast, but on the products themselves.

(b) The dimensions of the specimens to be submitted to mechanical tests must not only be small so as to make it easy for the tester to take them out of the whole casting, but they must also be maintained between certain practical limits so that the specimens are statistically isothermal.

(c) The number of tests thus localized must be multiplied as to permit in some way the survey of their mechanical topography, by a methodical and careful examination.

(d) This examination, the essential object of which must be a search for the weak or defective points, must be guided by our knowledge of the thermal history of the castings under consideration. This examination must be completed by a research at least qualitative, if not quantitative, of the unforeseen defects (especially blowholes).

(e) The specifications must show not only the average value of the mechanical characteristics in a certain region, but also its most unfavorable value (minimum or maximum, according to the case).

Conditions Resulting from Small Resistance to Deformation

80. As a general rule, the metals in castings—and more particularly cast irons—have a small capacity to resist mechanical deformation. This characteristic is sufficient to justify the rejection of certain methods and criteria, which are quite reasonably acceptable for metals endowed with a certain degree of malleability.

81. We have said before that tension tests of cast irons must be abandoned because of small resistance to deformation of cast iron. One might be tempted to consider this characteristic as a simple criterion in relation to the quality of cast irons as well as of steel, but for cast irons a small resistance to deformation is a common characteristic which necessarily varies between narrow limits. We then are led to magnify the deformations or use testing methods which might even accentuate them, with the object of reaching a greater degree of exactness in measuring this property.

82. The use of apparatus capable of amplifying with a great degree of sensitiveness, such as mirror devices, are not generally recommended in industrial practice. It follows that the second proceeding appears to be preferable.

83. It is for this reason, no doubt, that the testing of cast

iron in torsion has been advocated. Torsion is, in fact, a method of testing which is very simple and capable of measuring the deformations.

84. For the same reason, the flexure test on long specimens could be retained; but under present conditions of the foundry industry it does not appear to me (as I have said before in regard to testing by shock) that the capacity of deformation should be adopted to evaluate the quality of cast iron. In conclusion, I suggest entire rejection as acceptance tests on castings, all measurements of (a) per cent of elongation, (b) per cent of reduction in section area, (c) deflection due to rupture by flexure, (d) resistance to shock on un-notched bar specimens, and (e) angle of rupture in torsion.

General Condition of Methods for Acceptance Tests

85. Besides the conditions which are particular to the products for their acceptance, they must conform to certain other general conditions, as follows:

(a) A method of control must be, in principle, quantitive and not qualitative; it must give a means for figuring the quality of the product. It is the only way to avoid disputes. A qualitative method should not be admitted for acceptance unless all other methods of control are faulty.

(b) A method of control must be easy and simple in its application. The requirements of the industry, in fact, could not put up with certain means of control which are all right for the laboratory but otherwise costly because they necessitate a number of complex tools or the employment of highly specialized experts. All our efforts must be extended to reducing the cost of control operation and to make the results independent of the individual ideas of those making acceptance tests.

(c) The simplicity of acceptance tests must not exclude sensitive or exact measurements. For this reason, all conditions of the test (shop allowances in making the specimens, exactness, sensitivity, rules and characteristics in using the testing instruments) must be particularly and firmly fixed and scrupulously respected.

IV—THE NEW METHODS

86. The preceding considerations allow us to make a choice of the methods which are at present available to take the place of those we have condemned. These methods must be divided into two distinct classes, as follows:

(a) The so-called control methods.

(b) The methods of investigation of the more or less apparent foundry defects.

87. I shall mention, only as a memorandum, a third class of tests, special application tests, whose objects consist in verifying the fitness of products for their particular use, such as for watertightness of certain pieces or the experimental firing of projectiles.

Methods of Control

88. Having eliminated the shock and tension tests, we can make a choice between the following methods:

Micrographic examination
Torsion
Punching
Compression
Static flexure
Shearing
Hardness

Micrographic Examination.

89. It is highly regrettable that the micrographic examination, because it cannot be expressed in figures, cannot be admitted as a method for the acceptance of castings. There is, in fact, no process of control which is more productive of value in the foundry than is this one. Today a simple micrographic examination gives to the foundryman perhaps the best information on the quality of the casting.

90. It must not be forgotten that technical micrography is no longer confined to a laboratory. Micrography is within reach of everyone, and, like chemical analysis, it should be practiced by every foundryman.

91. For this reason I believe that, even for the acceptance of the foundry products, it is convenient to make a micrographic

examination at least for the sake of information. Because mechanical characteristics are identified by the proportions of the elements, by their distribution, by the size of the grains and their impurities—in a word, by the structure of the metal—this kind of examination would, with advantage, take the place of the old system of examining the fracture, a method which is still practiced today, but also a qualitative test whose interpretation is difficult and unreliable.

Torsion and Punching.

92. These tests, which had been suggested by Sipp[38] and by Rudeloff,[42, 44] appear to have been discarded, as has been pointed out by Portevin;[23] for one reason, because they were causing compound stresses, and for another reason, because they required specimens of relatively large dimension, too expensive to machine and not meeting the needs for a topographic study of the products; and further, because of the fact that their correct manipulation appeared rather difficult in industrial practice.

Compression.

93. The compression test, which I have mentioned before as essentially logical for cast irons, could be applied on cylinders of dimensions smaller than the 16×16 mm. (0.63×0.63 in.) specimen widely used in France, because it can be used on machines of smaller power. These small pieces, which are much easier to handle, nevertheless permit control of the homogeneity. However, because these testing methods are practically equivalent to the ball hardness test, it is clear that the latter is preferred because it does not require the casting of specimens, besides having the advantage that it can be applied without destruction of the castings.

94. In conclusion, there remains only the three methods advocated by Portevin and by the French commission for the testing of cast irons, these being (a) static flexure, (b) shear and (c) hardness. These three methods are actually used in France, and, used in combination, they are sufficient to every need.

Static Flexure and Shear.

95. It was Fremont[3] who, in 1909, drew attention to the weak points of our old methods and suggested the substitution of the static flexure and the shear on small specimens taken from

the castings. He also worked out for these tests the methods of carrying them out, and these have since been adopted without alterations.

96. The static flexure test of Fremont is made on specimens of $35 \times 10 \times 8$ mm. ($1.37 \times 0.39 \times 0.31$ in.), supported by two supports 30 mm. (1.18 in.) apart. The flexure is applied in the middle of the specimen by a knife edge. Under these conditions the stress developed in breaking the specimen does not exceed 1000 kg. (2205 lbs.) for the best cast irons.

97. A magnifying apparatus permitting a reading on a convenient scale gives the deflection as a function of the loading. The diagram obtained (Fig. 5) gives, then, not only the load causing

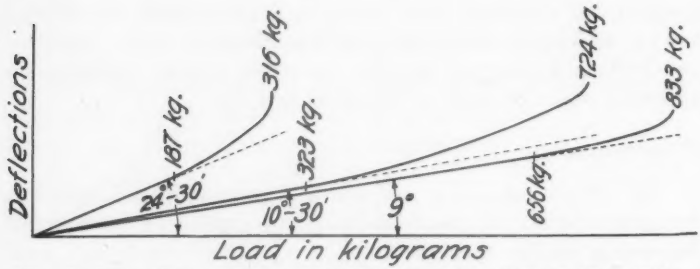

FIG. 5—THREE TYPICAL DIAGRAMS OF TEST BY STATIC FLEXURE, EACH MADE ON A VERY DIFFERENT QUALITY OF CAST IRON (FREMONT).

the rupture but also the modulus of elasticity, the measurement of which is given by the cotangent of the angle made by the rectilinear part of the diagram from the origin, with the axis of the load. It supplies the means of finding out, by approximation, the elastic limit as well as the deflection at its point of rupture, which indicate the capacity for deformation.

98. With this method the static flexure test gives the most complete information regarding the mechanical properties of cast iron. It fulfills the requirements we have pointed out as characterizing a good testing method for the foundry products; but, unfortunately, because of their machine-finished requirements, it necessitates the use of costly specimens which make any number of tests almost prohibitive.

99. Fremont also, taking as a basis the results of systematic

tests showing that the resistance to shear is proportional to the resistance to flexure, suggested the substitution for the flexure test of a simple test by shear on specimens taken out with a trepanning tool. This shear test is made on cylindrical specimens having a section of 25 mm.^{2} (0.984 in.^{2}), between two flat cutting blades which run parallel in a guillotine.

100. On the same specimen it is possible to make successive tests every 3 or 4 mm. (0.118 or 0.157 in.) This test, therefore, will show the heterogeneity of the specimen. The only precautions to be taken are:

(a) The use of specimens fitting well into the guillotine, in such a manner that direct shear is obtained without sensible flexure.

(b) The assurance of a perfect guidance of the cutting blades.

101. It is clear that the accuracy of the tests is the greatest when the above conditions are nearest obtained.

102. In the last few years there have been discussions without end concerning the experimental errors in the shear tests of Fremont, while before Fremont no one took any notice of considerable errors in testing cast irons to tension tests. In industrial practice, as I myself have noted many times, we find tensile machines having errors in calibration of more than five per cent, while all sorts of causes of errors have been carefully sought in the shear test of Fremont, even with regard to the influence of the marks left by the trepanning tool on the specimen.

103. I shall not stop to consider these fruitless discussions. In order to have it well applied, each testing method needs experimental caution and supervision of the testing machine. If we want results perfectly accurate, it is necessary that, whatever method we use, the machine should be well made, well calibrated and well kept, with a conscientious operator and carefully finished specimens accurately gaged.

104. I shall only point out that it is particularly easy to apply correctly the Fremont shear test, because its operation is very simple. In cases of very accurate tests, we are compelled to finish the trepanned specimen on the lathe, but in general this precaution is useless in industrial practice.

105. Finally, it is opportune to point out that the test by

simple shear as adopted by Fremont is always easier to carry out correctly than is the double-shear method used by Rudeloff[42] and Elliott.[43] In the double-shear method it is difficult, in fact, to obtain the perfectly simultaneous action of the blades on the two sections, which condition is indispensable in avoiding accidental deflections.

Brinell Test.

106. The systematic application of the ball hardness test to foundry products is due to Portevin.[8] This method, which is operated without any difficulty, is now very familiar to all. It has the great advantage of not causing the destruction of the castings submitted to test. Better still than the shear, it is easy for the control of homogeneity.

107. Because of the isothermal reasons mentioned above, a ball of 10 mm. (0.394 in.) is used under a load of 3000 kg. (6615 lbs.) It is not necessary, as in testing steel products, to fix the duration of the application of the load, because of the low plasticity of cast iron; the diameter of impression is practically independent of the time of application of the load.

The Testing Machines.

108. In 1909 Fremont devised two very simple testing machines for static flexure and shear tests. These machines have been criticized, perhaps not without reason, as too crude. No doubt Fremont, who was a pioneer of the testing methods which bear his name, purposely devised a kind of inexpensive machine to be used by small founders. Nevertheless, even without the improvements brought about by Thyssen,[40] these machines are accurate enough in most cases.

109. However, when it is a question of deciding whether a product has to be rejected or accepted, when interests often important are involved, it is imperative to operate under such conditions as to give all guarantees of accuracy.

110. In the last few years several manufacturers have built some very satisfactory machines to carry out the Fremont tests. In France, M. Guillery invented some remarkable devices giving, by means of circular coordinates, a flexure diagram capable of correcting (by a wedging-up screw) the errors resulting from

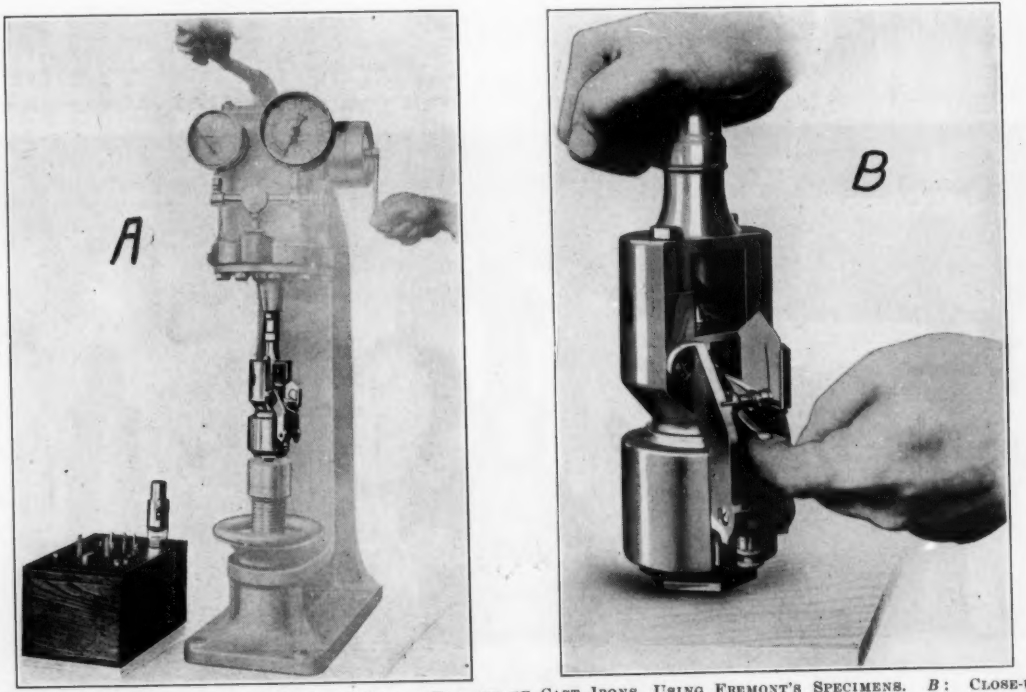

FIG. 6—*A*: GUILLERY'S APPARATUS FOR TESTS OF STATIC FLEXURE OF CAST IRONS, USING FREMONT'S SPECIMENS. *B*: CLOSE-UP VIEW OF GUILLERY'S APPARATUS.

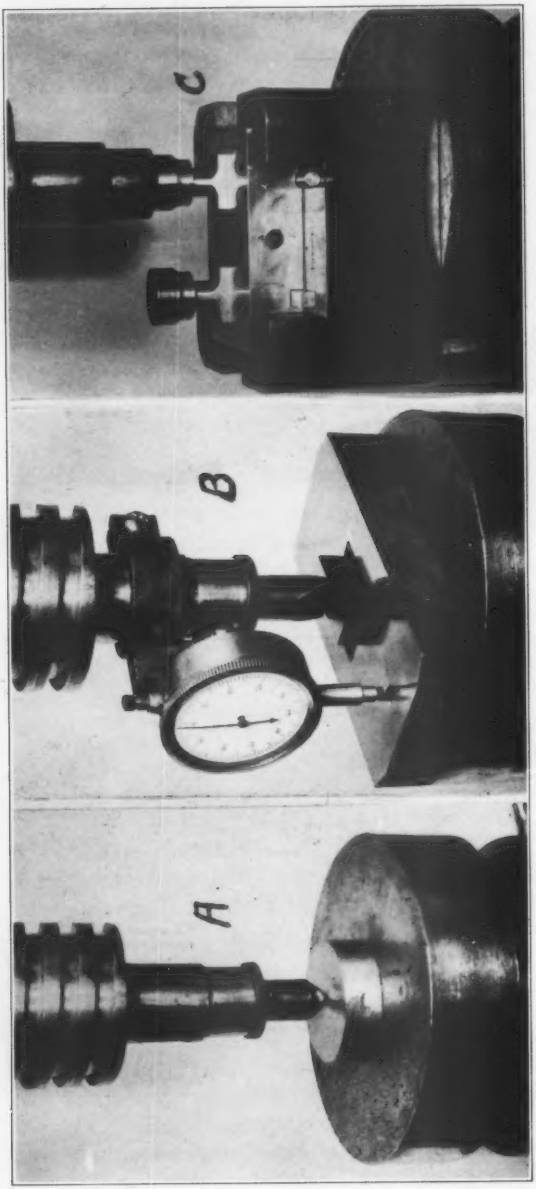

FIG. 7.—PERFORMANCE BY THE SAME MACHINE IN THREE TESTS ON CAST IRON. *A*: HARDNESS TEST. *B*: FLEXURE TEST. *C*: SHEARING TEST.

imperfections in the shear specimens. These devices, which can be added to most of the testing machines for compression or for the ball hardness, and in spite of considerable improvements made, still answer sufficiently the economic conditions required by Fremont. (Fig. 6).

111. For my part, I always carry out the three tests (flexure, shear and hardness) of cast irons, in each case using the same pressing machine. On this machine I have fitted small and very simple devices purposely made for this use (Fig. 7). It is noticeable that the arrangement made for static flexure tests does not necessitate a recording apparatus. I shall explain the reason for this further on.

112. The deflection measurement is given by a dial indicator graduated in hundredths of a millimeter. With such devices carefully placed, I have always obtained very remarkable results. I took the precaution, however, of having the specimens machine finished on the lathe to $\pm$ 0.01 mm. (0.00039 in.)

113. Not the least advantage of the new methods of testing cast iron such as proposed by Fremont and by Portevin, is to have all three tests made on the same "universal" machine. Being of small power, it consequently has a small cost of operation.

Methods of Determining Defects in Foundry Products

114. Although the "cat" had to be given up in favor of more scientific methods of exploration, nevertheless the method of measuring apparent density (invented by De Montalembert[2] to disclose the blowholes in cannons) is still of current use. This simple method, which does not necessitate any costly piece of machinery, is not in danger of being supplanted by X-ray metallurgy, the employment of which would be justified only in exceptional cases.

115. Observation of the duration of the tone given out by cast iron when struck may point out slight cracks, as it does in the case of steel, but it does not permit the giving of a final judgment in case the defects are of some importance.

116. A select method of revealing the blowholes, which unfortunately is restricted to ferro-magnetic metals, appears to be that of magnetism. It often is quite easy to build up electromagnetic "feelers" which give a variation of the flow when passed

over a blowhole, so as to generate in an induction coil connected with a galvanometer an electromagnetic force which can be observed and eventually magnified.* Even without using the method of magnifying called "thermoionic," it is possible to utilize with advantage the classic proposition of Hugues (of which I have elsewhere mentioned an adaptation particularly productive to thermomagnetic and magneto-elastic researches.† The arrangements to be adopted evidently are dependent on the shape of the pieces.

117. Pieces to be tested also can be roughly magnetized and observation then made of the magnetic field obtained by dipping the pieces in petroleum which has in suspension some very fine cast-iron filings.

118. Finally, the method** invented by M. Roux for the control of weldings also is very happily adaptable to searching out foundry defects. This method consists in placing the piece to be observed between the poles of an electromagnet and spreading over it some iron filings. The iron filings are spread uniformly so as to reduce the resistance to magnetic current. The iron filings concentrate over the blowholes, giving a superficial picture of them.

V—THE MECHANICAL PROPERTIES OF CAST IRONS

Selection and Mode of Application of the Resulting Testing Methods

119. Since 1909, Fremont, as a conclusion of his methodical experiments on a great number and variety of samples (the qualities for most of which he knew), has supplied information about the mechanical properties of cast irons which, to my knowledge, have been confirmed by all the experiments made after him. The greatest part of these data are shown in a striking manner by Figs. 5 and 8, which I reproduce from his papers. I shall review them again here by completing them with the remarks made by Portevin and myself.

(1) In the first place, *a quality of cast iron is better for use than another in proportion as its resistance to static flexure is greater.*

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* Peltier, J., "Researches of the Defects in Ferromagnetic Pieces," *Comptes Rendue de l'Academie des Sciences,* 1929, pp. 701, 1086; 1930, p. 1052.

† Nicolau, P., "Contribution to the Thermomagnetic Analysis—Scale of Induction of High Sensitiveness," *Revue de Metallurgie,* 1925.

** Roux, *Comptes Rendue de l'Academie des Sciences,* Oct. 24, 1927.

(2) *The resistance of cast iron to flexure is proportional to its resistance to shear.*

120. It is only necessary, then, in classification of cast irons, to have determined the resistance either to flexure or to shear. This shows why, when we can secure no more complete information by the flexure test breaking load, it is of advantage to use instead the shear test, which is much easier and cheaper.

(3) *Moreover, shearing resistance is proportional to tensile resistance* (*Fremont*[5]). This relation, the theoretical interest of which is perhaps open to discussion, deserves to be specially mentioned for two reasons, as follows:

(a) It is of a nature to satisfy those who, being used to basing their calculations for design on their knowledge of the tensile strength properties (according to an ill-founded but generally accepted practice), do not think it is possible for them to give up the tension test in favor of the shearing test.

(b) It has been disputed by different authors.

121. This controversy has prompted me to cite, in support of Fremont's thesis, some of my personal experiences. I have discovered that the ratio $\frac{Rc}{R_T}$, the resistance to shear to the resistance to tension, always is greater than 1, according to the quality of cast iron, sometimes even reaching 2. However, having noticed that this ratio was greater when cast irons were of a poor quality, I thought that my determinations of the resistance to tension R^T were affected by a decreasing error, as the cast iron was of a better quality.

122. On the other hand, I made some comparative tests on shear and tension on bronzes containing different percentages of tin, and I was fortunate enough to make tests on samples which, all things being equal, had been cast in defective conditions, so that the specimens for tension test, from the same samples, broke prematurely with a very small increase in their length. I have found out that, for normal specimens, the ratio $\frac{Rc}{R_T}$ was always very near to 1. On the other hand, for abnormal specimens this ratio varied from 1 to 2.

Table 1

COMPARISON OF THE RESISTANCE TO TENSION AND TO SHEAR OF DIFFERENT BRONZES

Composition of Bronze		Shear	Tension		
Copper, %	Tin, %	Rc	Rt	A%	$\frac{Rt}{Rc}$
88.28	11.6	26.3	21.4	7.3	1.23
89.21	10.67	32.7	21.2	7.1	1.60
89.76	10.11	23.5	17.2	5.9	1.36
90.90	8.93	26.7	20.3	10.7	1.32
91.57	8.27	27.0	26.4	26.4	1.02
91.64	8.19	26.7	27.5	26.3	0.98
91.70	8.14	26.6	25.3	19.0	1.07
92.02	7.80	26.2	14.0	4.2	1.88
92.48	7.36	24.9	25.9	23.1	0.96
92.52	7.33	26.2	26.5	24.6	0.98
92.97	6.86	26.0	27.4	29.2	0.95
93.63	6.21	24.4	26.3	32.9	0.97
93.92	5.90	25.3	21.1	30.9	0.95
94.28	5.56	25.5	25.5	30.6	1.00
94.55	5.29	23.6	26.2	32.0	0.90
95.56	4.79	22.8	18.8	14.8	1.20

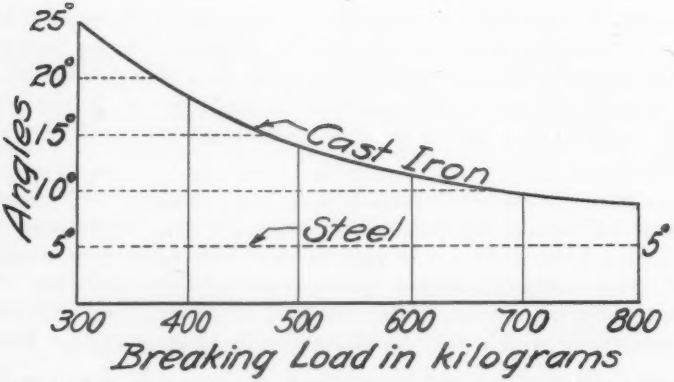

FIG. 8—VARIATION OF MODULUS OF ELASTICITY OF CAST IRONS, AS A FUNCTION OF THEIR RESISTANCE TO FLEXURE (ACCORDING TO FREMONT). THE ABSCISSAS REPRESENT THE BREAKING LOADS, WHILE THE ORDINATES ARE THE ANGLES WHOSE COTANGENTS MEASURE THE MODULUS OF ELASTICITY.

123. Table 1 gives a summary of the average values of the results of such tests. The figures corresponding to the defective samples have been underlined.

124. Consequently, I think that in principle the equality of the resistances to tension and to shear is a general property of foundry products, all of which have a capacity to resist deformation which is more or less low (the reduction of the sectional area, due to elongation, is almost nil).

(4) In cast irons, *the modulus of elasticity is proportionally lower when they are of an inferior quality.* (See Fig. 12.) Consequently, the modulus of elasticity varies in the same way as the resistance to flexure, to shear and to tension.

125. Fremont has thus found that the angle whose cotangent gives the measurement of the modulus of elasticity, varies as a function of the resistance to flexure, as shown in Fig. 8.

126. Personally, I have found that good pearlitic cast irons

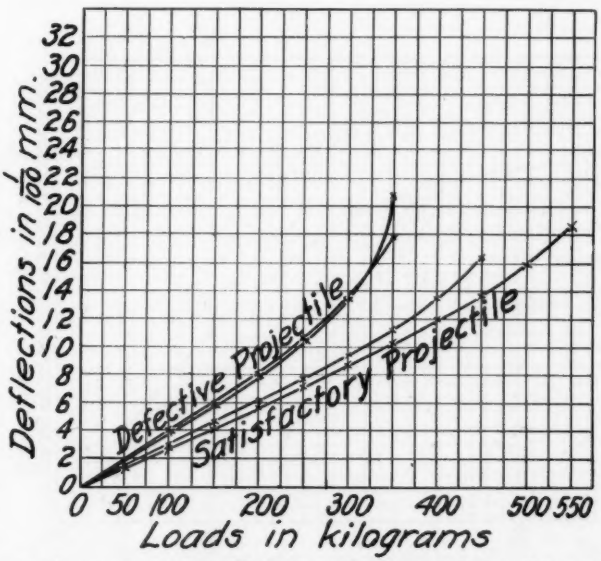

FIG. 9—DIAGRAMS OF STATIC FLEXURE OF PROJECTILES GIVING SATISFACTORY RESULTS AND OF DEFECTIVE PROJECTILES ON FIRING TESTS.

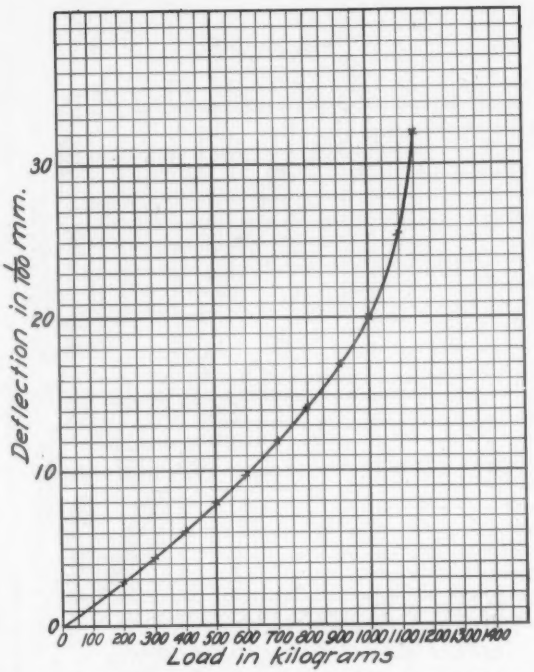

FIG. 10—RESULTS OF FLEXURE TESTS OF CAST IRON BY FREMONT, USING A 5-TON CAPACITY AMSLER MACHINE, SPECIMENS 35 × 10 × 8 MM. (1.37 × 0.39 × 0.31 IN.) DEFLECTION MEASURED BY A "COMPARATOR" INSTRUMENT PROVIDED WITH A DIAL.

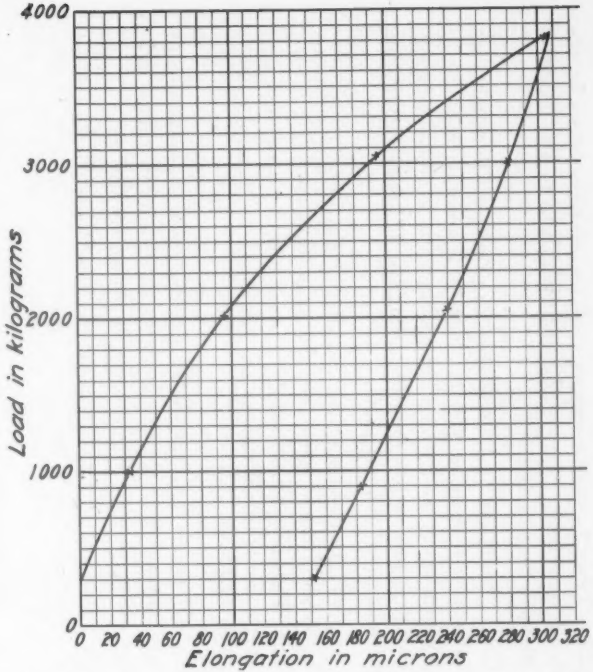

FIG. 11—DIAGRAM OF FIRST STAGE OF TENSION OF A CAST IRON SPECIMEN OF 20 MM. OBTAINED BY USING CHAVIN EXTENSOMETER.

always give a modulus of elasticity beyond 14,000,000 lbs. per sq. in. although in some cast irons the modulus may be as low as 5,600,000 lbs. per sq. in. I also have noticed that the projectile which met the firing test had, in general, a modulus of elasticity superior to that of defective projectiles.

127. It is, however, necessary to make ourselves understood as to what we call modulus of elasticity of cast iron.

128. When the deformations are sufficiently magnified, we find that the diagrams of flexure, or tension, do not show a rectilinear part. Hooke's law is not applicable for cast irons. The modulus of elasticity, represented as the limit of the ratio $\frac{dP}{dl}$ of the variation of the load to the variation of the corresponding length, varies from one point to another of the diagram.

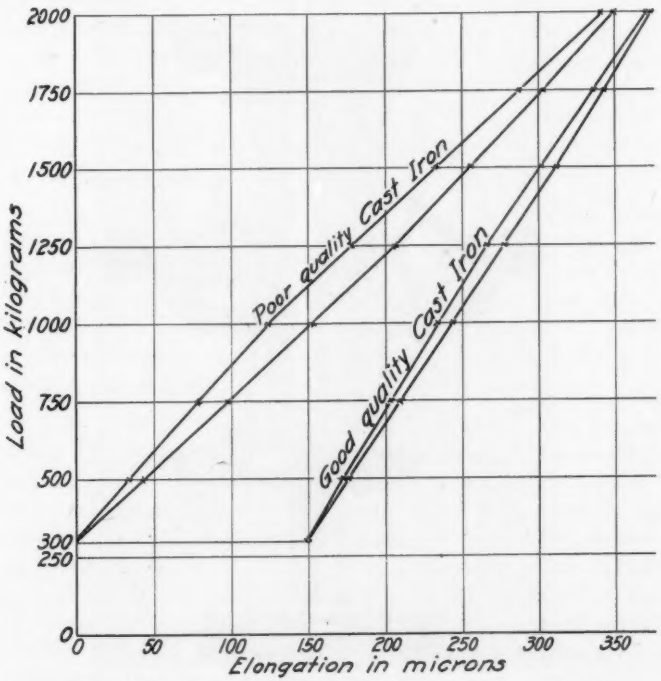

FIG. 12—CYCLES OF TENSION OF TWO SPECIMENS OF CAST IRON.

129. As an example, some diagrams are given (Figs. 10 and 11) of flexure and tension on a large scale. The diagrams were obtained with the arrangement which I have already described. To lay out the tension diagrams I have made use of a remarkable extensometer with two mirrors, invented by my associate M. Chanvin (Fig. 13).

130. An advantage which this instrument has over the one with Martens mirrors, from which it originated, is its ease of being

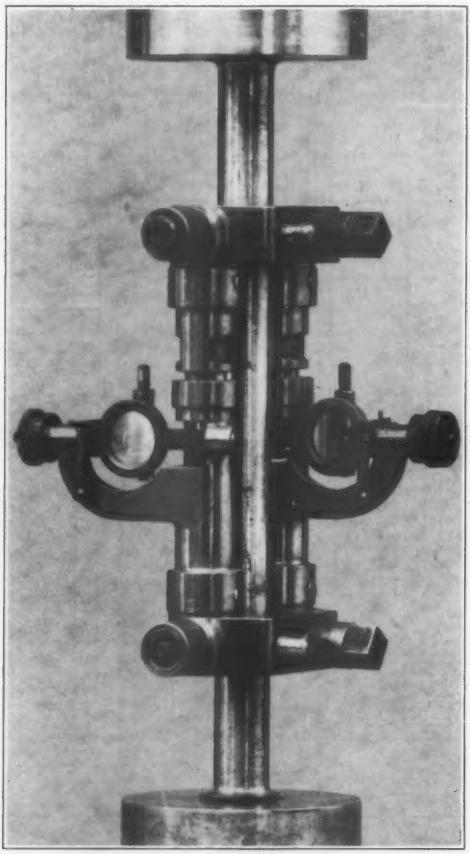

FIG. 13—CHANVIN'S EXTENSOMETER.

placed on the specimen and in being calibrated directly with the assistance of Johansson blocks. Its magnification, depending on the distance between the graduated scales from which the reading is taken and the corresponding mirrors, can easily be set to a reading of $1000X$.

131. With this instrument, having established that cast irons have, properly speaking, no elastic limit because the latter seems to be lower as the correctness of the measurements increases, it was thought that in order to determine the modulus of elasticity in tension it would be preferable to operate on two bars previously purposely made elastic by stress. Fig. 12 gives the tension cycles thus obtained for both good and bad cast irons. It is noticeable that these cycles do not have straight lines. According to the point where the modulus is determined, a difference up to 3,000,000 lbs. per sq. in. can be found.

132. It is necessary, then, to come to an understanding on the conditions of this determination, *viz.*, size of the cycle and region in the diagram where the measurement is to be made. It seems to me that in order to remain in the field of the practical deformations we must preferably define the modulus as that measured at the origin of the diagram, after having fixed a cycle of tension of which the maximum load is not more than 7000 to 14,000 lbs. per sq. in.

133. Owing to a general and well-known law, the modulus thus measured is always considerably lower than the one expressed by the angular coefficient of the tangent to the curve of first tension. On the other hand, it is to be noticed that the cycles of tension of Fig. 12 are affected by an "hysterisis" which is greater when the cast iron is of a poorer quality and its modulus of elasticity is lower.

134. Finally, these diagrams are marked, as I have frequently stated, by a plastic flow which, to my knowledge, has never been noticed by any experimenter. Under the maximum load of the cycle there takes place, after a number of reversals, a purely elastic elongation. This phenomenon, which in a way is the inverse of resilience, shows in particular that it is not possible to base a general method for the determination of the elastic limit on the finding of the load under which the first appreciable straight line occurs. For cast iron, in fact, this line does not necessarily correspond to permanent deformation.

135. I thought it useful to mention these types of investigations on cast iron properties which are of a speculative order. However, it is clear that in industrial practice in general it is not possible to consider carrying out such delicate tests. In spite of the improved instruments called "elasticimeters," such as that of Chanvin, the determination of the modulus of elasticity is still too long and delicate to use in our specifications.

136. Nevertheless, the numerous tests carried out have led me to believe that the modulus of elasticity is an essential criterion, and one very sensitive as to the quality of cast irons.

137. Perhaps it is possible to make an indirect use of the modulus of elasticity for the classification of cast irons by remarking that this characteristic is proportional to the square of the pitch of the sound produced by striking it, so that we could accept cast irons by their sound. Another simpler way of making use of the modulus of elasticity for the acceptance of cast irons consists in measuring, in the Fremont static flexure test, the deflection under a load small enough so that the permanent deformations are negligible.

(5) Although, strictly speaking, there is no such thing as elastic limit of cast irons, it can be found (as Fremont did—Fig. 5), by registering the flexure diagram on a medium scale, that it is possible to determine (on this diagram) approximately *a proportional limit, which is the higher as the cast iron is of a better quality for use.*

(6) I have already pointed out that, with regard to the shock test, *a high deflection at rupture does not necessarily characterize a good quality of cast iron.* That is why it appears to me futile, as a rule, to fix (as has been done until now) either a minimum of the resistance to shock or a minimum deflection of rupture, which is almost the same thing. Figs. 5 and 9 are a confirmation of this opinion.

(7) Thus, on the one hand, the elastic limit and the modulus of elasticity increase with the quality of cast iron, and on the other, the capacity to resist deformation, which means the deflection of rupture by flexure, is not a sure criterion to judge the quality.

Table 2

EFFECT OF SLIGHT VARIATIONS IN HARDNESS OF CAST IRON ON RESISTANCE TO SHEAR

Brinell Hardness Nos.	Resistance to Shear.
232 ± 4	30.0
196 ± 5	24.0
$174 + 10$	20.2
153	18.0
135 ± 3	3.7
135	18.8 to 20.3

Consequently, we are led to believe that, among the cast irons capable of a certain amount of loading to rupture, the best ones are those whose deflection is the less under the same flexure strain.

138. When applied to the deflection test to rupture, this theory is in agreement with the results I have mentioned. However, as has been rightly remarked by Le Thomas, this argument cannot be relied upon in all cases because certain "annealed" cast irons, capable of a certain elongation until rupture, are in practice very interesting products.

139. In order to limit the decrease of both the modulus of elasticity and the elastic limit, which in all cases seem to characterize a bad quality of cast iron, without eliminating, however, cast iron with a high elongation, I propose to limit the value of the deflection under a load to a point a little above the limit of the practical proportion—which could, for instance, be fixed at about two-thirds of the required breaking load.

140. Therefore, for cast iron there should be specified a load of rupture to flexure *above* a certain minimum F, characteristic of the quality requested, and a deflection *below* a certain given value f, under the load $= 2/3\ F$. For certain special cast irons perhaps it could be specified in addition that the deflection should be above a given value f_r.

141. Together, these three conditions perhaps would permit us to define a field of ideal cast irons. However, it is necessary to remark that a minimum f_r and a minimum f often make the two conditions contradictory, and in the ordinary casting it would be difficult to satisfy both. In principle, since cast irons are not used because of their capacity to resist deformation and especially

because of rigidity, it is the determining of a maximum f that matters most.

(8) *The resistance to compression* and also the *ball hardness,* which is nothing else but a localized compression, *classify cast iron in general in the same manner as the resistances to flexure or to shear.*

142. In order to facilitate their performance, it is reasonable to say that the ball hardness test should be substituted for the compression test. However, it is proper to remark that in case of cast irons of low hardness, some variations in their hardness, hardly perceptible, might correspond to considerable variations of the other mechanical characteristics. Some data on this point are given in Table 2.

(9) The resistance to wear is perhaps one of the most interesting among the characteristics of cast iron to be determined.

143. Unfortunately, it does not appear that there exists now a laboratory method of supplying information on this complex characteristic with any kind of reliability and under such experimental conditions that they can always be reproduced correctly and exactly. According to certain tests, the hardness would vary in the same degree as machinability and resistance to wear, but this fact does not appear to be general. It is well known that two cast irons, equally hard, and like two pieces of steel, may offer noticeable differences in their resistance to wear.

144. The question of the resistance of cast iron to wear is at present one of greatest concern to the French Commission on Testing Methods of Cast Irons, and it is the object of many researches. However, it would be premature to mention them now.

145. By what I have said, I have tried to give in brief form the qualitative relations existing between the different characteristics, having in view the determination of those permitting the classification of cast irons of the same order, thus avoiding needless repetition. I shall not give the empirical formulas established by various experimenters to show relation between the results obtained by several kinds of tests. It is clear that these formulas are not applicable except in a very limited field where the constitution and composition of cast irons for such formulas have been established.

146. In a general way, it is understandable that if we know any two characteristics of the material, A and B—of which are known, for instance, because of their alloy, the curves representing the variations as a function of a parameter (such as its composition)—it is always possible to determine around a given value of p a field more or less limited, in which A and B can be represented as a first approximation, by a linear function of p.

$$A = m\ p \div n$$
$$B = m'\ p \div n$$

147. Consequently, in the same field, there exists also a linear relation between A and B. The research of such relations is of a very limited interest.

148. The preceding considerations on the mechanical properties of cast irons permit us to fix the conditions for the application of the new methods for the acceptance tests of foundry products and the results to be obtained from them.

149. The micrographic examination, together with the chemical analysis of which it is the necessary complement, can only be held as a valuable information; but we shall have to make use of the ball hardness test and of that of shear to make the mechanical map of the products. The ball test, for the reason that it does not spoil the elements on which it is applied, can easily be generalized. However, because of the lesser sensitiveness of this test, we must admit that a certain lack of hardness will not imply rejection of the casting, which would occur if the shearing test, made on a specimen taken out from the neighborhood of the ball hardness test, shows a lower figure than allowable. In other words, it is on the results of the shearing test that we shall have to judge the ability of the casting to resist breakage.

150. This single criterion of the quality would not be sufficient to judge with certainty as to their mechanical value, even when we have made sure that they are well in the group we have set for their composition and constitution by microscopic and chemical analysis. In order to have full confidence in the value of the castings, it is imperative to make some few static flexure tests on the elements or parts of those regions which we presume are the weakest.

151. As a verification of the data secured by the test of static flexure, I propose to make sure that both the modulus and the

Table 3

APPROXIMATE PHYSICAL PROPERTIES OF GOOD-QUALITY PEARLITIC CAST IRON USED IN MAKING SHELLS

				Maximum.
Brinell no.	Minimum	160	Avg.	175
Resistance to shear, kg./mm.²	Minimum	24	Avg.	29
Resistance to shear, lbs. per sq. in.	Minimum	34,000	Avg.	41,000
Resistance to static flexure, kg./mm.²	Minimum	620	Avg.	680*
Maximum deflection in mm. under 400 kg.	Maximum	14	Avg.	12
Maximum deflection in in. under 8820 lbs.	Maximum	0.55	Avg.	0.47

* Fremont test.

practical limit of elasticity are sufficiently high to specify a maximum figure for the specimen's deflection under a static load of about two-thirds the specified breaking load.

152. In order to give a concluding example, I will mention that a good quality of pearlitic cast iron, similar to steel and generally used for the fabrication of projectiles, must possess, according to numerous tests, the characteristics at the bottom of the shell on the middle of a radius as shown in Table 3.

153. Finally, when it is a question of manufacturing a large number of identical castings, such as in the making of projectiles, the proposed methods should be applied in the following order:

(a) Chemical analysis periodically made for each lot to supply information.

(b) Research of physical defects, preferably by magnetic methods and, if possible, on all parts.

(c) Exploration by the ball hardness test of all the sections, not only on the surface but possibly on the "heart" of them. For instance, if it is a question of projectiles, by the hardness test, after cutting off the sink head, on the bottom at the half radius.

(d) Classification of the sections in two groups: (1) including the sections possessing a degree of hardness above the minimum acceptable, and (2) including the sections of lower hardness.

(e) Methodical exploration with the assistance of the shearing test, to be made on the sections of each group of low hardness. The result of this examination

has as an object the acceptance or rejection of the group to which the individual casting belongs.

(f) When the shearing test is satisfactory, a test to be made on the same section, in the region having the weakest resistance. Such test to be a static flexure test the object of which would be to make sure that the deflection under a load of about two-thirds the assumed breaking load is below the *maximum* specified.

(g) Microscopic examination of some sections.

(h) Eventually, the test as a whole of a number of units under actual service conditions.

154. It is clear that, according to the importance of the products in question, these requirements should be reduced or increased. This is a simple scheme which must be adapted with judgment to each particular case.

SUMMARY AND CONCLUSIONS

155. The choice and the way of applying the methods of control of castings is the result of two essential characteristics:

(a) Heterogeneity.

(b) Low capacity for deformation.

156. The test should be made on the castings themselves; not on specimens cast separately.

157. Tests should be localized and repeated in order to give in some way the mechanical survey of the products.

158. The localization of the tests should be extended to apply to the major part of products of the most ordinary dimensions, without losing sight of the necessity of having the section tested statistically isothermal.

159. The essential aim of the control of the mechanical quality of any fabrication is the investigation of the weak or defective points. Therefore, one should take into consideration not only the average values of the mechanical characteristics measured, but also those values which are the most unfavorable (maximum or minimum, as the case may be).

160. In the majority of cases this investigation should include the following:

(a) A qualitative examination by a proceeding which shows the physical defects (density, magnetism, X-rays, etc.).

(b) A methodical examination of the products; this examination must be guided, on the one hand, by our knowledge of the casting conditions as well as of the general laws of the solidification; and, on the other hand, by the qualitative examination previously made.

161. In order to decide on the acceptance of foundry products, the methods of control must be quantitative, of easy application, but exact.

162. The micrographic examination, although unacceptable for this application because it does not give numerical results, must be carried out for the sake of the required information, together with the chemical analysis of which it is the necessary complement.

163. The flexure test by shock should be rejected because it gives a measure of the capacity for flexure, which is not always a criterion of quality for the metals of low resistance to deformation. In the majority of cases, it can be said that cast iron is of a better quality for use in proportion as its resistance to shock is low, and *vice versa*.

164. For the same reason, all mechanical characteristics which supply a measure of the resistance to deformation ($A\%$ and Σ in the tension test—deflection at the breaking point in the static flexure test; angle of rupture in the torsion test) do not constitute, in general, a criterion of quality of the castings.

165. The metals and the alloys of low resistance to deformation, whatever is the method of stressing them, have but one form of rupture, "intergranular rupture without appreciable sliding." The result is that the resistances to rupture supply a classification independent of the method of stressing. That is why, especially for cast irons, the resistance to tension and to shear are equal and also proportional to the resistance in flexure.

166. Strictly speaking, one cannot talk about the elastic limit of cast irons. The more exact are the measurements of the permanent deformation, the lower is the elastic limit of cast iron. Cast irons, however, are of a much better quality in proportion as the permanent deformations are delayed, which means that, for a given load, the permanent deformations are smaller.

167. The modulus of elasticity of cast iron increases with the quality (from about 5,600,000 to about 21,000,000 lbs. per sq. in.). This modulus seems to be their best evaluation.

168. The test by static flexure constitutes the best test of foundry products. As specified by Fremont [specimens of 35 × 10 × 8 mm. (1.37 × 0.39 × 0.31 in.) on supports spacing 30 mm. (1.18 in.)], the static flexure test is satisfactory for all the conditions previously mentioned and by itself alone is good enough to classify cast irons according to their true values in relation to required qualities (except when and where resistance to wear is involved), namely:

Resistant to rupture
Modulus of elasticity
Practical elastic limit

169. I propose to fix, in this test, the following:

(a) A *minimum* of the breaking load.

(b) A *maximum* of the deflection under a load of about two-thirds of the breaking load specified.

(c) Occasionally, besides conditions (a) and (b), a *minimum* of the deflection at the rupture.

170. The complete test of static flexure, which is relatively costly to make, should be reserved for the investigation of the sections which a topographic study previously made has pointed out as defective.

171. The methods chosen (because they are simple, practically economical and exact) to carry out this topographic study, are as follows:

(a) The ball hardness test, using a ball of 10 mm. (0.39 in.) under 3000 kg. (6615 lbs.) load as proposed by Portevin.

(b) The test by simple shear.

172. As proposed by Fremont, the latter test is made on cylindrical specimens of 25 mm. (0.98 in.) square section, which can be taken out of the section by trepanning and which do not need finishing in the machine shop before carrying out the ordinary tests.

173. The Fremont and Portevin methods, as adopted for the foundry products (hardness, static flexure and shear) are also

to be specified for cast irons. For the control of the manufactured products of any given material it is generally absolutely necessary, in fact, to make use of the same methods which have been used for the studies of their properties as well as for figuring out the characteristics of this material.

174. The search for a simple method, capable of giving in reasonable time and space certain and exact information about the resistance to wear of cast irons, is still imperatively needed.

175. The new mechanical methods of Fremont and Portevin, of testing foundry products, have received the approval of the French foundrymen. They have been adopted by the largest French departments (War and Navy, for instance), and there is reason to believe that the old methods of evaluation by specimens separately cast and tested by shock and in tension will be definitely abandoned in France very shortly. Thanks to their technical value, already proven by an important number of experiments, these new methods will greatly contribute to the betterment of the castings, which, after all, is the sole object of our attention and efforts.

176. Endowed with means for logical investigations which are of easy application, the foundrymen are now in a position to proceed with scientific analysis of the ruling factors relating to properties of castings. Many foundrymen already are reaping the benefit of having abandoned the old methods.

177. From a technical point of view essentially, and as one who is strictly disinterested, I sincerely hope that American foundrymen, who have always been at the head of the progress, will study earnestly the tests instituted by Fremont and which, after twenty years of study and discussion, we have come to advocate.

178. At this hour, when international cooperation in every field has become an imperative necessity, it will be highly desirable to formulate an international standard for the testing of cast iron, leading in a way to the creation of a common language—a genuine technical "esperanto"—between the foundrymen of all nations which would greatly facilitate the exchange both scientifically and commercially. The welcome granted by several countries to the French methods permits us to hope that their theoretical and practical value will soon be recognized by the foundrymen of all nations who are anxious to improve their products as demanded by the ever-increasing needs of the mechanical industry.

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DISCUSSION

ORAL DISCUSSION

J. W. BOLTON:[1] Some few months ago we had an opportunity of going over the data of shear tests presented by various investigators: Elliott, Fremont, and various others. We tried to summarize those tests to determine the relationship between shear test results and of tensile tests, transverse tests and others of that type. I found that no one investigator's results were the same as any other's.

Anyone who has had experience with shear test work, speaking of the method of application of such a stress, should see that that is not likely to be the case. The shear test is likely to be higher unless the cross-bending stress is there; that will not show true shear, but cross-bending.

[1] Metallurgist, The Lunkenheimer Co., Cincinnati.

In Mr. Nicolau's paper there is mention of how easy it is to prepare a shear testing sample. Let me say once and for all, as a matter of my own personal opinion, that the shear test is very useful in prospecting work or testing pieces of casting from which one cannot get as large test specimens as he would like to have. However, when it comes to specification work, that is a different story. Before American foundrymen give any encouragement to the use of the shear test specifications, I believe they should investigate rather carefully.

In our laboratory the double shear test has been tried out, and with it we get a very good alignment. The specimen is prepared by grinding to a close fit. The block that does the actual shearing has heavy oil on it, for it is practically impossible to drive the block down if there is no lubricant on it.

We have had occasion to run quite a large number of samples varying rather widely in their characteristics, as regards both analysis and strength. Our results lead us to agree with Mr. Shaw that, with iron such as high-phosphorus iron or mottled iron, or perhaps some type of heat-treated iron, very peculiar results are likely to occur, because the shear is really a combination of compressions and tensile stresses. However, using this double shear block with ordinary runs of iron, we found a very close correlation between the tensile and the shear; that is, very consistent results in 96 or 98 per cent of the cases.

R. S. MAC PHERRAN:[2] In commenting upon this paper by Major Nicolau, I wish to state that it is extremely refreshing to get so many new ideas as he has presented to us. The paper is well worth reading.

The author favors dropping the tensile test and also the bending by shock test, and he favors a static bending, shearing and ball hardness test, these to be used in conjunction with a micrograph and chemical analysis. He also makes several very interesting suggestions for the locating of internal defects.

His criticism of the tension test is that it is almost impossible to pull the specimen entirely in line. The question at once arises as to whether this is a defect inherent in the test or whether most of these objections might not be removed by the use of a ball-and-socket joint with our new types of machines and the use of easy fillets. Personally, I have always favored the tension test.

I agree with Major Nicolau, however, that the greatest care should be taken in conducting this tension test. The surfaces should always be carefully prepared.

It might be of interest to recall that some years ago the late Mr. Diller and the speaker conducted a series of tests on the effect of fillets. We took test bars cast in the same mold and gated from the same gate. One bar in every two was machined up with the then standard fillet, and the second bar with a fillet of much greater radius, with which Mr. Diller and the speaker were experimenting.

We found, on an average of twenty tests of each kind of fillet, that the bars made with the new easy fillet averaged 4000 lbs. per sq. in. higher than the companion bars made with the then standard fillet.

[2] Chief Chemist, Allis-Chalmers Mfg. Co., Milwaukee.

I may add that I have seen many bars pulled when the machines were out of line, and most of the specimens were breaking in the fillets. Too great care cannot be taken in conducting these tension tests.

I regret to say that I have had no personal experience with the shear test of cast iron. I once saw Mr. Ronceray make a half dozen shear tests on pieces drilled from the same piece of cast iron. These test pieces were not re-machined after being drilled from their original position, and they were sheared in the condition in which they were removed. The maximum variation between those pieces, as I recall it, was 8.5 per cent.

WRITTEN DISCUSSION

JOHN SHAW:[3] Your chairman has asked me to state the British standpoint regarding the test methods advocated in this paper. As they consist simply of methods advocated by a limited French school since 1922 and contain no new facts or make any attempt to answer the very real objections raised at the last International Congress, only a brief restatement of those objections are possible.

Every paper submitted on this question has viewed the matter from one angle, *viz.*, the production side. In all cases, the material has been so surrounded by cupola, chemical and micrographic control that it would be changed if any one test should yield irregular results. Under these conditions a shear empirical load figure can be fixed, after a comparative trial with the older methods of testing, but only for the particular composition and machine in use.[4]

There never has been any objection raised to the use of the shear test as an auxiliary test for shop routine work, and it has been clearly stated that under the closely controlled conditions that obtain in the above papers, concordant results could be attained.[5] The opposition has been caused by the desire of its sponsors to impose the shear test on other nations as the dominant test in any international specification.

Any specification of this type, which may be used for castings differing from tunnel segments or corporation gulleys to engine work, must comply with at least two fundamental conditions, as follows:

(1) That the breaking load figure can be translated into tons per square inch tensile (the figure generally used by the designer), or yield some other figure of known physical properties that can be used to compute the strengths and necessary thickness of scantlings for the safety of the design.

(2) That the breaking load of this test will enable the inspecting engineer—who has nothing to do with the production, and must in many cases rely on one or two sample tests—to pass with confidence the ma-

[3] Southsea, England.

[4] Audo, L., "Notes on the Manufacture of Steam Cylinders for Locomotives and Piston Rings for the Paris-Orleans Railway Co.," *Proceedings,* Institute of British Foundrymen, vol. 20, p. 140, 1927.

[5] *Proceedings,* Institute of British Foundrymen, vol. 22, p. 553, 1929.

terial as complying with the strengths set out in the specification and designer's computations.

From the evidence collected over two years' experiments with all types of composition, we came to the conclusion that the shear test complied with neither of these conditions. Although the results of the above experiments were published in 1929, no effort has been made to disprove the conclusions stated in any of the three papers given since that date, although there has been a gradual change of front.

Fremont stated: "The shearing and static bending tests are in harmony." Ronceray[6] states: "Shearing is proportional to the transverse and the tensile is equal to shearing, consequently a shearing test is quite satisfactory for inspection purposes." LeThomas[7] stated that there was a close relation between shear and tensile. LeThomas[8] stated: "It is illusory to look for any relation whatsoever between shear strength and tensile strength." LeThomas was reported[9] in a review of the Liege congress of 1930 as depreciating the attempts made to find formulas giving an absolute relation between the results of the various test methods, and advocating that each test should be taken on its merits.

From this, combined with our experiments, it may be accepted that the shear test result bears no constant ratio, with different compositions, to either the transverse or tensile results. We have found that these ratios may vary from 1:1 to 1.9:1; also, that in any table giving both tensile and shear results, the highest ratio of shear over tensile or transverse is when the latter are low, thus giving a fictitious value to the shear results.

In one table the first nine bars, 2x1x36 inches, all failed to register the minimum load required (28 cwt.), and the material cast from these irons would have failed. Yet all these same bars yielded a shear test result that would proclaim the iron as extra strong. Under these conditions, the position of both designer and inspector is obvious.

I do not want to say much about the machine used except that the design has been changed quite frequently. The type as used by Elliott, Bolton, and Rother has been condemned as not yielding correct results. Two machines of this type, and one more elaborate, were tested on the same piece of iron. The two former gave 16.22 and 17.15 tons, respectively, while the last machine gave 21.7 tons per sq. in. It is not possible to check the correctness of the machines as one could the old transverse machines. The least wear leads to a bending movement and an incorrect result.

Much has been written of the advantage of testing pieces from the actual casting, especially when that casting varies much in section on various parts. It is well known that the thicker sections, due to the slower cooling, will have a lower strength per square inch, at least with some compositions.

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[6] Ronceray, E. V., "New Methods of Testing Cast Iron," *Proceedings*, Institute of British Foundrymen, vol. 15, pp. 26-51, 1922.

[7] LeThomas, A. E., *Testing Cast Iron*, TRANSACTIONS A. F. A. (1926), vol. 34, pp. 690-741.

[8] *Proceedings*, Institute of British Foundrymen, vol. 22, p. 500, 1929.

[9] Report of 1930 Foundry Congress, Liege, Belgium; *The Foundry*, Aug. 1, 1930, p. 95.

In stating the strength per square inch of the various sections, one is apt to forget that the very reason that lowers the strength, *viz.*, the extra thickness, by its bulk much more than offsets its weaker structure. That is, if one takes a bar of 1-inch diameter, 12 inches long, and the diameter is increased to 3 inches for another 12 inches, that bar either in transverse or tensile always will break in the 1-inch strong metal rather than in the weaker 3-inch part, due to the increased area of the latter.

A wrong conclusion often is drawn from a test piece taken from the center of a thick section, whether the test is the ordinary tensile or shear. Referring to a table given in the *Foundry Trade Journal*, it will be found that from a 5½-inch diameter bar, tensile tests taken from the outer 1¼-inch thickness yield 10.2 tons, while from the center the test only reaches 6.2 tons. Obviously, if the bar was tested full size, the breaking load would be approximately 9 tons per sq. in.*

There has never been any desire on the part of the I. B. F. to impose their specification on other national organizations. They recognize its limitations, but thus far they have found no other specification that has given as much useful information. Every fresh development will receive their careful consideration and, if proved better, will be accepted for general use.

JAS. T. MACKENZIE:[10] In paragraph 134 of Major Nicolau's paper, in commenting on the plastic flow of cast iron when the first few cycles of stress are applied and its subsequent elastic behavior, he says that to his knowledge this has never been noticed by any experimenter. This was described by Bach in his book on "Elasticity and Strength," the first edition of which, as I remember it, came out in the Eighties. In 1926 Sugimura published quite an extensive work on the elastic behavior of cast iron, at both ordinary and high temperatures. The writer published a short paper on the same subject in 1929 in the *Proceedings* of the American Society for Testing Materials.

Bolton also has published some figures showing plastic deformation followed by elastic behavior. In fact, there is a limit on plastic deformation in several piston ring specifications, which have been in force for some time.

It is personally gratifying to us to see the author's enthusiasm for the modulus of elasticity, or, as has been proposed, the "stiffness ratio" in the transverse test. The author, being primarily concerned with shells where stiffness is a prime consideration, wishes to place a minimum on the modulus of elasticity. The writer, being connected with the cast iron pipe industry in which high flexibility is one of the most desirable properties, has been equally partial to a maximum figure for modulus of elasticity. In fact, a maximum is specified in the U. S. Government master specifications for centrifugally cast iron pipe.

Major Nicolau suggests that two moduli be specified, namely, a

* The area of 5½-inch diameter, which is 23.76 sq. in., less area of 2½-inch diameter or 4.9 sq. in., which gives 18.86 sq. in. area. This area of 18.86 at 10.2 tons per sq. in., plus the 4.9 sq. in. area at 6.2 tons per sq. in., gives a total of 222.75 tons, which, divided by the total area of 23.76 sq. in., gives 9.3 tons per sq. in.

[10] Metallurgist, American Cast Iron Pipe Co., Birmingham, Ala.

modulus at, say, two-thirds of the ultimate load, and a modulus at the ultimate load. It might very well be that a specification for the minimum modulus at the two-thirds point could be followed by a maximum figure at the ultimate, which would give stiffness at the useful range and at the same time would allow the maximum amount of bending between the useful range and the failure point, which would be similar to the elongation of steel. The elongation of steel is in no part an indication of its usefulness in service, but a safeguard against sudden failure in case of excessive loading.

I should like also to object to the use of the words "good" cast iron and "bad" cast iron in place of a more definite statement of the quality intended. For instance, a bad cast iron for a shell would be a good cast iron for cast iron pipe, and *vice versa*.

The main objection to the standardization of the shear test for an inspection test would appear to lie in the difficulty as to an agreement from what point in the casting a shear test should be taken. The suggestion is true, of course, of all specimens taken from the casting. If we are going to take shear, tensile, or transverse tests on the poorest possible place in the casting, then we must set new limits for values at these points, especially in designs which allow the meeting place of thick and thin sections, or even of two thick sections.

Tensile strength now specified at 30,000 lbs. per sq. in. probably would have to be reduced to 10,000 lbs., and transverse moduli of rupture now stated at 90,000 lbs. would have to be reduced to 30,000. This is not an insuperable objection, but there would have to be a much greater understanding in the minds of the engineers as to the properties of castings in general and of cast iron in particular before any agreement could be reached on such matters.

There is so much good in the ideas of the French proponents of the shear test and ball hardness test for acceptance that it is with difficulty that I bring myself to criticize these proposals. However, my personal belief is that the separately cast bar would cover the situation if the foundryman would make the greatest possible use of the French ideas in topographical surveys of his castings in conjunction with the real foundry study of the influence of shrinkage and casting strains on his castings.

The field of the test on the castings themselves as units has hardly been cleared of the stumps and brambles. Cast iron pipe and most of the castings used for water and steam, being of cylindrical shape and adapted for this method especially, have been thoroughly tested as castings and the results correlated with the results of separately cast test bars and of small specimens cut from the walls. The large body of miscellaneous castings, however, are still dependent on long and doubtful conditions of service for an estimation of their value, and this is very difficult to tie up with the individual quality of the casting, even when we get the service records.

I cannot quite agree with the aspersions Major Nicolau has cast on the tensile test. It is our experience that even a very small tensile specimen, such as used in cast iron pipe with a diameter of only 0.25 inch, gives beautifully consistent results when used with a machine-threaded grip and spherical blocks in the head of a testing machine.

Use of the Robertson shackles also seems to give wonderful results—in fact, more consistent results than the shear test. I believe it is easier to measure the tensile specimen after it is broken than it is to insure a thorough fit of the shear specimen in the guillotine. Certainly the shear does not give any more information than the tensile test, except for the fact that the tensile specimen, in general, can be broken only once, whereas a shear can be broken every few millimeters.

I doubt very much that Major Nicolau will be able to persuade the world that a shock test on cast iron is of absolutely no value, and that a good shock test means a poor cast iron, and *vice versa*. The subcommittee of the American Society for Testing Materials is now engaged in working on this question in collaboration with the British Cast Iron Research Association and the French Technical Foundry Association, and we believe much good will come of it.

The drop test must be interpreted in the light of the other values and is by no means a conclusive test on the value of the cast iron when used alone. However, with the information of the tranverse test, or tensile, or shear, at hand, the drop test or other impact test is a very valuable corroborative test. I do not think, however, it should be confined to a 1-1/2 inch section, such as is used by the French ordnance and later adopted by the U. S. Ordnance Department for test of shells, but should be standardized on different size specimens bearing some rational relation to the casting, if separately cast bars are used. If the specimen is taken from the casting, either the small Charpy or Izod would be suitable if the statistical nature of the data be borne in mind.

WRITTEN CLOSURE BY AUTHOR

P. NICOLAU: It is always hazardous to claim priority in scientific matters. However, to avoid all confusion, I wish to clarify the expressions in paragraph 134 of my paper. The yielding under a constant load, characterized by a permanent deformation, is and indeed has been well known for some time, as is also the phenomenon of "accommodation" of a test piece subjected to a few cycles of deformation.

The cycles of tension shown by Fig. 12 of my paper refer, precisely, to gray iron that has been made elastic through "accommodation," after having been subjected to a few cycles of tension from 0 to 2000 kilograms. What characterizes these cycles is the small deformation observed under the maximum load, an essentially elastic deformation. This should not be confounded with the plastic flow, characterized by a permanent deformation, which is observed, in general, on cycles of tension before the accommodation is complete.

It is this phenomenon of elastic flow—one could say elastic viscosity (an inverse phenomenon to the reactivity, which is of such importance in certain materials, such as rubber)—which I have considered as new, as far as gray iron is concerned. However, if this has already been described by Bach, Sugimura, Bolton, and by Mr. MacKenzie himself, which I have not yet been able to verify, I can only congratulate myself on my agreement with so many eminent specialists, remembering again the very old adage that "there is nothing new under the sun."

As Mr. MacKenzie points out, the idea of the quality of a casting is essentially a relative one. A casting that is "good" for pipes is not necessarily good for artillery shells, and *vice versa*. The important thing is to determine the mechanical properties capable of characterizing castings in all cases. For each application, the limiting values of these characteristics should be set differently.

I am glad to note that Mr. MacKenzie, like myself and in accord with all recent resolutions of the International Foundry Congress held at Milan in September, 1931, considers the modulus of elasticity as an essential criterion of the quality of castings. I am convinced that, in a general way, it is well to stipulate in the specifications a minimum value of this modulus, corresponding to the conditions of use of the products concerned in each case, but it is possible that for certain special applications it would be well to fix a maximum. Such undoubtedly is the case of the pipes to which Mr. MacKenzie refers.

Such an exception can only confirm the general character of the modulus of elasticity as a criterion of the quality of castings.

The shock test as applied to castings has not, on the contrary, a general character. I fear that my remarks on this test have been misunderstood.

I do not claim that a good shock test result always signifies a bad casting, and inversely. I have only shown that this could sometimes occur, and I have sought to set forth the reasons for this anomaly. Thus, in perfect accord with Mr. MacKenzie on this point, I think that the shock test used alone is not conclusive as to the value of the casting, and that the results cannot be interpreted except as one compares them to the results of the bending test.

I even want to go so far as to say that the information that it can give seems to me to be contained in the conclusions that can be drawn from the static flexion test. As no effect of fragility comes into play in the shock test—for the reason that, on the one hand, the casting has only one mode of rupture, and on the other hand, full bars are made use of—it seems to me that this test is, on the whole, only a means of measuring what in France is called "live resistance" to flexion, that is, the area of the diagram of static flexion.

Without a doubt, the experimental study which the sub-committee of the American Society for Testing Materials proposes so opportunely to make in collaboration with the British Cast Iron Research Association and the Technical Association of the French foundry industry, will bring a substantial contribution to the question of the shock test for castings. In the light of the results obtained it undoubtedly will be possible to determine definitely the practical value of this test.

I should not like to close these remarks without underscoring that, in spite of some divergencies of view, especially concerning the tension test, the ideas of Mr. MacKenzie on several fundamental points are in perfect accord with the views that I have outlined in my paper. This agreement is for me an especially flattering and valuable encouragement.

Some Observations on Preparation and Use of Synthetic Sand

By L. B. Knight,* Chicago

Abstract

The use of synthetic sand, which has increased extensively in the past few years, has emphasized the need for information as to how this material can best be prepared. Mechanical mixing to coat the sand grains with the bonding material is a necessity. Many foundries have found it advantageous to start their rebonding program with facing sands, later extending the work to the entire quantity of sand used. To use this material, definite standards of permeability, bond strength and moisture must be established and maintained. An illustration of the practice in one plant is cited. The development in continuous systems is discussed, showing the different methods used.

Introduction

1. It is not the purpose of this paper to analyze specific problems arising from the preparation and use of synthetic sand, but rather to present a few practical observations made in many foundries where synthetic sand has been successfully used. The author realizes that it is beyond the scope of any one paper to treat with all the problems arising from the use of synthetic sand and a bonding agent. If, as a result of this paper, interest can be aroused in the several foundries so that papers will be presented at future meetings treating with special features in the development and continued successful use of a rebonding program, the main purpose of this paper will have been realized.

Widespread Use of Synthetic Sand

2. The use of synthetic molding sand has increased extensively and rapidly in the last few years until today there is practically no class of ferrous casting which is not cast somewhere in synthetic sand. As the deposits of natural bonded sand, suitable for molding, are exhausted, the foundryman is

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Note: This paper was presented and discussed before one of the sand control sessions at the 1931 convention of the American Foundrymen's Association.

forced, due to lack of this natural material and the high cost of transportation, to investigate the possibilities and application of one of the several bonds used for reclaiming used sand and for making synthetic sand.

3. The cost of disposal of waste sand, and the volume of new molding sand to be handled, also are problems which cause the foundryman to search for more economical methods of obtaining a suitable sand for molding.

4. From the development of the use of the several bonds for synthetic sand, it would appear that the use of synthetic sand is the answer to the problem. Then the question which faces us is: How should we use the bond to obtain maximum economy and efficiency by its use?

5. Hereafter in this paper we shall use the words "re-bonded" or "synthetic" sand to mean sand which has had one of the commercial bonds added to the silica grain to give it the required bond strength.

UNIFORMITY OF PRODUCT

6. There is no basic difference between natural molding sand and synthetic molding sand. Both are made up of silica grains, clay and moisture, but with synthetic sand it is possible to obtain a more uniform product. Uniform grain size, quality and quantity of clay, and moisture percentage, may all be controlled in synthetic sand. Thus, it is possible always to obtain a sand with definite standards of permeability, bond strength and moisture, provided proper mechanical mixing apparatus is used to obtain and maintain that result.

7. Also, the usual amounts of impurities, such as iron oxide, lime, etc., found in natural sand are absent from synthetic sand. This results in a more refractory product, providing a pure silica sand and high-grade fireclay are used, which in turn means less burning-on and cleaner castings. The fireclays used for bonding have a fusion point approximating 3000 degs. Fahr., while the clay in most natural bonded sands will fuse at temperatures several hundred degrees below this figure.

MECHANICAL MIXING NECESSARY

8. It has taken nature ages, in the case of uniform natural molding sand, to coat each silica grain with a film of clay. When

we use synthetic sand we must give each grain its coating of clay and distribute the bond uniformly throughout the mass of the sand. This requires mechanical mixing, and there are several machines on the market recommended for this purpose.

9. The batch-type muller, with its concentrated mulling or rubbing action, is used most widely and successfully for preparing rebonded or synthetic sand. The intensive mulling and rubbing action coats each silica grain with its film of clay and develops the maximum strength of the bond used.

10. This means that for a given bond strength less bond may be used when mixed in a batch-type muller than when mixed by any other method. The less bond required to develop a given bond strength, the higher the resulting permeability will be, and, other variables being constant, the cleaner the casting poured in this sand will be, with resultant lower costs.

START A REBONDING PROGRAM WITH FACING SAND

11. A rebonding program should be approached in such a way that the best results may be obtained with a minimum of expense and difficulty. This means somewhat of an educational program for the molders and operating men. Many foundries have found it most profitable to start their rebonding program with their facing sands. Here the volume of sand affected is small and the results may be closely checked and necessary changes in the mix made with a minimum of expense.

12. Definite standards of permeability, bond strength and moisture must be established. This is best accomplished by observing the results obtained with various sand and clay mixtures used as facing sand. The tests should all be conducted with the ultimate aim of obtaining a mix which will give a sound casting with the best possible surface.

13. Thus, a mix is desired with the minimum of bond necessary to obtain a draw from the pattern and prevent swells, cuts, washes, etc., when the casting is poured. Permeability should be high enough to allow the free passage of all gas from the mold, but not so high that penetration will occur. It has been found in practice that the moisture range for fireclay-bonded synthetic sand is from 4 to 5.5 per cent, and where bentonite clay is used, 2.5 to 4 per cent.

A PRACTICAL ILLUSTRATION

14. Figures on mixtures and standards used in a gray iron shop making farm implement castings are as follows:

15. Daily additions of silica sand, clay and sea coal are made to the heaps. These additions are made up of two parts of silica sand—say, Ottawa No. 2—and one part clay bond and one to three sea coal mulled with about 2 per cent moisture.

16. The amount of moisture (2 per cent) in the mix is so small that the addition is practically like meal. This simplifies the spreading of it on the heaps and helps to distribute the bond evenly throughout the heap.

17. It is essential that the moisture content in the addition be kept as low as possible where concentrated mixes of sand and clay are used. Otherwise, the chance of clay balls forming will be greatly increased.

18. It was further found in this shop that, if the addition was carefully spread over the length of the used heap, and the heap cut over before moisture was added, that about 25 per cent less bond could be used to obtain the required bond strength. Then water was added and the heap cut over several times.

19. Samples were taken from several places in the heap and it was found that the sand was more uniform in permeability, bond strength and moisture when this procedure was followed, than when the moisture was added without first cutting the heap and addition dry.

Amount of Sand Addition Required

20. The amount of bond in the addition (33 per cent) cuts the volume of addition to the heap necessary to maintain the required bond strength. Natural bonded sand usually contains 12 to 15 per cent clay. On that basis, one-half to one-third the usual volume of sand addition is necessary to furnish a required amount of bond to the used heap.

21. There may be some question as to whether or not this is the best method of adding the bond to the heaps, but where it is not possible to treat all the sand, as in a continuous system, the above outlined method has many advantages.

22. The decreased volume of sand addition eliminates the

handling of a great amount of waste sand. The handling of both the addition and waste sand is reduced to a minimum. With proper supervision and care exercised in making the additions, the practice as outlined will give satisfactory results, as is evidenced by the fact that the foundry referred to has followed this practice for more than a year and a half.

23. Tests showed that a much smoother casting would result if the pattern were faced. The heap sand was mulled with additional sea coal and the mulling action increased the bond strength of the sand without further addition of bond.

A Sand Specification

24. For a casting weighing approximately 150 lbs. (mold is sandslinger rammed) the following specifications have been established and are maintained as closely as possible:

Heap Sand

Permeability	Shear Strength	% Water
80-90	1.2 to 1.4	5.0

Facing Sand

32 parts heap sand
4 parts sea coal
mulled 5 minutes

Permeability	Shear Strength	% Water
60-70	1.5 to 1.7	5.0

25. With sand held to the above specifications, and with the rebonding program followed as outlined, satisfactory results were obtained. A clean, sound casting resulted with a considerable decrease in scrap loss and cleaning time over previous practice.

26. In a foundry where the work is not done on a continuous system, or where they have no central sand-preparing plant where the sand is mulled, it is necessary to face the pattern, except in some types of light castings. In many cases where sand-handling and conveying equipment has been installed without provision for mulling all of the sand in the system, it has been

necessary to have a battery of muller-type mixers to prepare facing sand, because the condition of the sand as it came from the molders' hoppers was not uniform enough in quality to produce sound, clean castings.

FACING PATTERN IS COSTLY PRACTICE

27. The cost of the necessary labor to prepare and distribute the facing sand to the molders, as well as the molding time lost by the molder in facing the pattern, makes this a costly practice. The recent trend, however, has been to make all the sand in the system a facing sand by installing muller-type mixers for the preparation of the sand in the system.

28. Too much attention has been given, in the past, to the conveying and distributing of the sand, and not enough attention to the heart of the system—the condition of the sand. It has been demonstrated conclusively at great cost to some few foundries that, regardless of how the sand is conveyed, if they cannot get sound, clean castings from this sand, the expenditure for the system should never have been made.

DEVELOPMENT IN CONTINUOUS SYSTEMS

29. The development in the use of synthetic sand in continuous systems, and the elimination of the facing operation, is best shown by citing a recommended installation for a shop operating continuously. In this shop one grade of sand should be used for both core and molding sand. A clay bond is used for addition to the silica sand.

30. After the casting is poured on a power conveyor, it travels to a central shakeout station where it is shaken out and the castings taken to the cleaning room. The sand drops through a grating onto a belt or apron conveyor with provision made to remove all metallic refuse.

31. The sand discharges from the magnetic belt conveyor directly into the boot of a centrifugal discharge elevator, then is elevated and discharged into a revolving hexagonal screen. Here core butts and other foreign material are removed and discharged down a tailing spout to a box on the floor.

32. The sand, after being screened, drops into a 100-ton storage hopper with two outlets into 2000-lb. batch-measuring hoppers located over a batch-type muller.

Control of Properties

33. The use of the batch mixer in the system insures positive control of the permeability, bond strength and moisture of the sand, and, because of the uniformity of the sand, all the sand can be made a facing sand. This eliminates the preparation of special facing sand and the facing operation by the molder.

34. All additions of bond, moisture and sea coal are made in the mixer and the operator can be certain that each batch of sand is exactly the same as each preceding batch. The mill turns out about 30 tons of prepared sand per hour.

35. The prepared sand discharges from the mixer onto an inclined belt conveyor into an aerator to aerate the sand, and from this aerator it discharges onto a belt conveyor where the sand is plowed off into the molders' hoppers located above the molding machines.

Different Methods Used

36. A number of different methods are used to establish and maintain a rebonding practice in a foundry. The method used is governed by the size of the foundry, the equipment on hand, the ability to purchase new equipment and the type of casting to be made in the sand.

37. Some plants merely put a small amount of bond on the poured mold before it is shaken out. The bond then is cut into the heap and tempering is done at the same time. This method usually is unsatisfactory, particularly if followed for any great length of time. Clay balls, non-uniform distribution of the bond and a considerable excess of the bond, all tend to result in a poorer quality of casting, a dirtier casting and greater scrap loss.

Concentrated Bond Additions

38. Other shops mull a concentrated addition of bond—say, two parts of sand to one part of clay, or even one part of sand to one part of clay—with a minimum of moisture (not over 2 per cent) and distribute this mix over the heaps as they would new sand, only in considerably less quantity, and then the heaps are cut over. This helps to distribute the bond more uniformly throughout the heap and practically eliminates clay balls.

39. The full efficiency of the bond is not obtained, however,

because the coating of the silica grains, except for those mulled with the bond, is left to contact with the more heavily bonded sand grains. This means that there is an excess of bond present which tends to result in dirtier castings than would be possible if this excess bond were not present. This method is used comparatively widely, however, and the results obtained are extremely favorable when compared with the practice of adding the raw clay to the heap.

40. The standards of permeability, bond strength and moisture should be set and maintained at a minimum in the sand that will result in consistently good results—sound, clean castings. If the sand is too close (permeability too low), an excessive amount of scrap will result, due to blows, scabs, etc. Too open a sand will cause penetration and rough-surfaced castings.

41. An exceedingly high bond strength showing an excess of bond will tend to decrease permeability and result in dirtier castings with excessive cleaning costs and a poorer quality of product. An excess of moisture will close up the sand, cause scabs, blows and dirtier castings with excessive scrapped castings and higher cleaning costs.

Minimum Clay and Moisture Desirable

42. The minimum amount of clay and moisture to develop the bond in the clay should be used. This minimum is determined by the results obtained when a casting is poured in the sand. The bond strength should be sufficiently high to give a clean draw from the pattern and prevent swells, cuts, washes, etc., in the casting, resulting from too weak a sand.

43. By far the most economical and satisfactory rebonding program can be carried out in a continuous system as described in this paper. In such a system, all the sand is subjected to the same treatment each time it is used. All foreign material is removed and absolute control can be maintained over the sand mixtures.

44. All additions of bond, moisture, sea coal, etc., are made in the mixer and each batch can be controlled by the operator and kept in the mill until it is in the same condition as the preceding batch.

45. Standards of permeability, moisture and bond strength can be established and maintained to extremely close limits.

Rules for Successful Use of Bonding Material

46. Once again, then, the successful use of a bonding material depends, first, on establishing proper standards of permeability, bond strength and moisture, and second, on maintaining these standards which have resulted in sound, clean castings with as little variation as possible.

47. The second rule demands the close attention of those in charge of the sand. Wherever possible, frequent tests of permeability, strength and moisture should be made. The results of these tests should be tabulated and distributed to the several foremen in order that they may be certain that the sand on their floors is in proper condition.

Permanent Test Records Advisable

48. A permanent record of all tests made should be kept for reference so that defects attributable to sand found in the castings after they have gone to the cleaning room, or even through to the machine shop, may be checked for variations in sand condition which may have caused them.

49. Some foundries plot daily curves of permeability, bond strength, moisture and scrap loss due to sand, *i.e.*, blows, scabby castings, cuts, drops, sand holes, etc. In a very short time (with other variables constant) it is possible to tell the approximate percentage of sand scrap by the chart of the sand tests, or *vice versa.*

Foreman-Laboratory Cooperation Essential

50. Close cooperation between the sand control laboratory and the foreman is essential. It also is necessary that no one but the man in charge of the sand be allowed to change the additions to a particular heap or the facing mix for a particular pattern, and any additions should be made on written order only.

51. Some of the larger foundries pay the "sand gangs" on a piecework basis. On such a basis, the sand laboratory issues to each foreman of a group of floors a slip calling for a definite quantity of heap addition or facing sand for each particular floor.

52. When the laborer delivers the amount of sand called for on the slip, he receives the slip; and when he turns it in to the timekeeper, it forms the basis on which he is paid.

53. This method of making additions insures against any one floor receiving more or less sand than the slip calls for, assuming, of course, that the average laborer will not work for nothing and will try to make all that he possibly can. In any case, it is a forward step toward positive control and maintenance of the standards of permeability, bond strength and moisture, all of which are necessary to insure sound, clean castings.

DISCUSSION

ORAL DISCUSSION

T. F. KILEY:[1] Has Mr. Knight had any experience in removing the fines from reclaimed sand, and has that factor given him any trouble?

L. B. KNIGHT: I realized, after this paper was submitted, that there was nothing in it about the removal of fines. In my opinion every sand-handling system that is installed should have an exhaust system as a part of it, not only for taking the dust away from the equipment but also for removing the fines from the sand. If this is done, the chances are that the sand can be controlled much more closely than any other way.

The dust system should have dampers, and it should be regulated so that it is operating uniformly all the time. If the same amount of fines is taken out, permeability and strength can be maintained, giving a very uniform sand coming to the mixer. The sand must be dry, however. Both air separation and screening are used successfully.

B. D. FULLER:[2] In paragraph 13 it is stated that a mix is desired with a minimum of bond necessary to prevent cuts, washes and swells. It is all right to talk about preventing cuts and washes, but I fail to see how a swell can be prevented by any mixture of sand.

L. B. KNIGHT: That may be a debatable question, but in some of the plants I have been in, and in one plant where I worked, we had a particular casting in which the only change made was a considerable increase in both the green and dry strength of the sand, and the swell was eliminated. There may have been other variables, but that was the only change we made to rectify it, and the swell disappeared.

B. D. FULLER: I fully realize that it would be possible to put an amount of bond into a facing which would give it a doughy condition if not properly rammed; one might say that was the cause of a swell. I think that is an extreme example, however. In any ordinary mixture it is not the sand or anything about or in the sand which will prevent a swell.

L. B. KNIGHT: One can have perfectly prepared sand, but, if not used right, one still will not get good results from it. The foundryman must

[1]Metallurgist, Brown & Sharpe Mfg. Co., Providence, R. I.
[2]Sales Representative, Whitehead Brothers Co., Lakewood, Ohio.

know how to use it; but, other things being equal, if the sand is not in proper condition, such a result as has been mentioned is apt to be obtained.

CHAIRMAN R. F. HARRINGTON:[3] There is a good deal of definite evidence that so little a difference as between a sand of nine pounds compression and one of ten pounds is sufficient to cause the sand to jolt easily or flow easily. The latter may cause a swell in the mold if there is a good deal of depth, as compared to the other case which will involve absolutely no swelling. Consequently, I rather think Mr. Knight's point is well taken and substantiated.

A. A. GRUBB:[4] We have made some observation of flowing quality, but it is rather early to draw definite conclusions. If we have two sands of equal bond strength as measured by the tensile test, and one of them is much lower in compressive strength, that one will flow better.

So far as our observations to date would allow us to draw conclusions, such a sand would ram down onto the pattern better. There would be less tendency to produce swells, a question of flowing value.

W. W. KERLIN:[5] In further reference to this matter of swells, the lack of strength in sand often is interpreted as a need for more colloidal bond. This is not always the case, because it may be that the sand is not capable of being tempered properly and a very important factor in this respect is the base grain distribution of the molding sand.

I have known cases where a mold of proper firmness could not be obtained and the addition of more clay bond increased the strength but produced swells. These cases generally were noticed with synthetic sands made up from a sand of fairly uniform grain size. When a sand of different grain size was incorporated in this mixture, it was found that the tempering properties were improved and it flowed better, especially in very deep molds where there are high vertical surfaces.

This indicates to me that a uniform distribution of sand grains will remedy some conditions where an increase in clay bond will not.

L. B. KNIGHT: The very first problem is to obtain a uniform grain size sand, if possible, and then the proper amount of bond with an optimum moisture content, usually under five per cent. One thing usually found in experimental work is that the optimum moisture content is much lower than that used in the foundry. In some tests we ran, the optimum moisture content was three to four per cent, and the actual range in the shop was four and one-half to five and one-half per cent.

I have not tried to go into any of these specific variables; I think that each one of them could be the subject of rather a voluminous paper. All the foundries which have gone to the use of synthetic sands should, by now, have plenty of records and be able to get from those records information of interest and value to the trade.

However, it will require work and effort on behalf of some of these people, and that is what we are trying to do—to get them to make these records public so that everyone can have the benefit of their knowledge as to the use of synthetic sand.

[3]Metallurgist, Hunt-Spiller Mfg. Corp., Boston.
[4]Grubb & Marshall, Columbus, Ohio.
[5]Metallurgist, Gray Iron Institute, Cleveland.

Report of A. F. A. Representative on Joint Committee on Investigation of the Effects of Phosphorus and Sulphur in Steel

To the Members of the American Foundrymen's Association:

Your representative on the Joint Committee on the Investigation of the Effects of Phosphorus and Sulphur in Steel hereby presents his annual report regarding work done under the direction of the Joint Committee, insofar as this work is of interest to steel casting producers.

The machining and testing of specimens for this entire investigation have been done exclusively at the Naval Experiment Station at Annapolis, Md., and at the Watertown Arsenal, Watertown, Mass., with the National Bureau of Standards cooperating in heat treating and other details. This work done by the government at its own expense represents much the major portion of the cost involved in the research. Necessarily, available appropriations influence the speed at which such work may be done. Naturally, it must be performed when it does not interfere with work more directly related to government needs.

After the laboratories at Annapolis and Watertown machined the coupons made by the Atlantic Steel Casting Co. for the phosphorus tests, gas cavities were uncovered. Nevertheless the specimens were tested. The defects prevented drawing conclusions to show relationship between phosphorus content and physical performance, consequently the presentation of a detailed record of the tests for your examination would be superfluous.

Although the results of the phosphorus casting tests have not been announced officially by the Joint Committee, it is proper for your representative to advise you of these facts at this time because of the desire of the Joint Committee to have replacement coupons made under such circumstances as would more nearly represent the commercial product of the steel foundry than did the original test material.

Note: This report was presented and discussed before one of the steel sessions at the 1931 convention of the American Foundrymen's Association.

The producing foundry has shown throughout satisfactorily cooperative spirit and has convinced the Joint Committee that the defective condition discovered is not typical of the commercial product of the plant or of the industry, but must be due to the extraordinary conditions surrounding the manufacture of 288 bars 12 inches long, from a total of eight heats, each of a different chemical composition.

Dr. Geo. K. Burgess, who is Director of the Bureau of Standards and has always been chairman of the Joint Committee, now is hopeful of the early resumption of work in manufacture, machining and testing. It therefore becomes desirable to arrange for replacement test material for the steel casting phosphorus tests. The Atlantic Steel Casting Co. recently expressed its desire to make the second lot of test bars. Doubtless its experience with the first lot of bars will be very valuable.

Your representative recommended to the chairman of the Joint Committee, the selection of the Atlantic foundry for the purpose mentioned, and this recommendation has been definitely approved. It is understood by the Atlantic foundry and by the Joint Committee that manufacture is arranged for conditional on a suitable method for financing the manufacture of the rough bars, such financing to be arranged for by the steel casting industry.

It is proper to state in this connection that the extra expense incurred by the foundry for making the original lot of rough bars was defrayed by the American Foundrymen's Association and the Steel Founders' Society of America, each organization reimbursing the Atlantic Steel Casting Co. for half of the cost. The share paid by the A. F. A. was accumulated through a solicitation made by letter addressed to all steel foundries not members of the Steel Founders' Society of America. In this way the A. F. A. collected $1010.00, of which $742.61 was used for reimbursing the foundry. Your representative was advised on May 1, 1931, by the A. F. A., that there was then in its custody, $278.22 remaining in the special test fund, which of course may be utilized as a portion of the cost of replacing the test material.

A more complete statement than that just made, covering receipts and disbursements in connection with the original phosphorus casting tests, was included in your representative's report to the 1928 A. F. A. convention, and was published in vol. 36 of

A. F. A. *Transactions.* In addition, a special report including this and other information was made in a circular letter dated May 1, 1928, addressed to all who had contributed to the cost of making the test material mentioned.

Your representative assumes that steel foundrymen generally are as desirous now as they were previously to ascertain the influence of phosphorus on the behavior of steel castings; and that, accordingly, the steel casting industry may be expected to raise the required amount for reimbursing the foundry which will manufacture the rough bars. It seems desirable to take early advantage of opportunities, which apparently will be open soon, for doing the expensive machine work. In the judgment of your representative, this justifies action at this time by steel foundrymen which will lead to the accumulation of the necessary fund.

In the latter connection it should be explained that the secretary of the Joint Committee a few months ago addressed a letter to each organization represented on it, soliciting a cash contribution for the general expense incidental to the committee's work. It was then explained that there were not sufficient funds available to the War and Navy Departments to push through expeditiously to completion, the project of the committee. For this purpose recently the American Society for Testing Materials contributed $500.00.

Your representative now recommends a suitable cash contribution from the A. F. A. for this purpose, in addition to some feasible arrangement for financing the work of making the rough test bars. It is believed that nominal contributions from organizations represented on the Joint Committee will have a very helpful effect.

Your representative believes the potentially economical aspects of the phosphorus casting tests fully justify the requested support of the steel casting industry as indicated above. If it should be demonstrated, for example, that it is safe for structural purposes to specify an appreciably higher maximum percentage of phosphorus than is now specified, those who make acid steel for castings should have available lower priced scrap than is now purchased.

Furthermore, the steel casting industry should, in the case suggested, reap an important advantage as the result of greater fluidity generally regarded as typical of steel containing a relatively high phosphorus content. Lower percentages of mis-run

and cold-shot castings, and the suitability of metal for pouring at a lower temperature than at present, with attendant advantages in respect to red shortness, should result.

Since the steel casting industry now has its attention strongly centered on every element related to economical manufacture, it seems particularly important to determine definitely, as soon as possible, the influence of phosphorus on the service behavior of steel castings.

Respectfully submitted,

R. A. BULL,
A. F. A. Representative on Joint Committee on Investigation of the Effects of Phosphorus and Sulphur in Steel.

DISCUSSION

CHAIRMAN JOHN HOWE HALL:[1] I do not know that there is any action required on this report. I would like to take this opportunity to answer questions that have been asked as to why the foundry industry should support this research into the effect of phosphorus on steel. I am sometimes told that there is plenty of information on file as to how much phosphorus we can allow in our steel, so that this research is unnecessary.

The trouble is, of course, that most of such information has been obtained and published by interested parties. The present investigation, on the other hand, will show the effect of phosphorus and sulphur as determined by entirely disinterested government laboratories and can be quoted as official, whereas there is no information now in existence that can be quoted as actually official and disinterested.

R. A. BULL:[2] In connection with the point just made, I do not believe that is true. We know, of course, from experience that 0.05 per cent phosphorus does not produce dangerous brittleness in ordinary structural steel, either wrought or cast, but I do not think we know where to draw the line between what is satisfactory and what is dangerous. The fact that by common consent we have used 0.05 per cent does not necessarily mean that that is the correct dividing line.

Obviously, this joint committee method of determining the facts and getting the information is the cheapest one that the industry concerned in the manufacture of the product can apply. It also has the very manifest advantage, as Mr. Hall pointed out, of determination by disinterested people, and that is coupled with general acceptance of the results obtained by the eleven national organizations represented on the joint committee, as in the case of the sulphur tests.

[1] Technical Assistant to President, Taylor-Wharton Iron & Steel Co., High Bridge, N. J.

[2] Director, Electric Steel Founders' Research Group, Chicago.

The Microscope as a Practical Aid in the Cast Iron Foundry

By Roy M. Allen,* Bloomfield, N. J.

Abstract

This paper deals with the use of the microscope in studying cast iron from the point of view of providing information for the practical foundryman and young metallurgist. The various foundry applications are listed, followed by a detailed discussion of the structures of various types of iron. Comparisons are made of structures observed in mild steel, high-carbon steel and gray iron. Formations of ferrite, cementite, pearlite and graphite in the various grades of iron are illustrated. The effects of the variations in the nature of pearlite are shown, and the various forms of carbon are discussed. Dendritic structures are explained. The forms of graphite in weak, medium, strong and alloy cast irons are compared. Rules are given for improving the quality of graphite structure. Chilled iron structures are illustrated. Effects of silicon, sulphur, phosphorus and manganese also are discussed in detail. Special rules and formulas for alloying elements are presented with illustrations of the effect of such elements on the structure of cast irons. An appendix is devoted to general instructions on the microscope, its construction, care and use, and on the preparation of specimens and the use of etchants in photomicrographic examination of metallurgical specimens.

*Consulting metallurgist.

Note: This paper was presented and discussed before one of the gray iron sessions at the 1931 convention of the American Foundrymen's Association.

1. This paper is intended for the cast iron foundryman in particular who has as yet no laboratory or research department with technically trained help for the control and improvement of his product, but who does desire to apply scientific methods, insofar as he may, in order to turn out a uniform, high-quality iron.

2. It is hoped that those already making practical application of the microscope in their laboratories will appreciate the point of view from which the paper has been written and be lenient in their judgment of the elementary presentation of the subject.

3. Some foundries, sensing the need for scientific control and desiring to be as up-to-date as possible, already have invested in a metallurgical instrument; but, lacking the necessary training, or a knowledge of how to obtain it, they are unable to utilize their equipment to the best advantage. Others also would like to do something along this line, but have considered it impossible to accomplish anything with a microscope, assuming that such instruments are only of value in the hands of an expert.

4. If it can be shown that much can be done with a microscope by any practical individual possessing a little knowledge of metallurgy, and that such knowledge is easy to acquire, this paper will not have been in vain.

5. Perhaps there is a third class, composed of those not yet having received a vision, and to whom anything dealing with the microstructure of cast iron is but "Greek," who can be led to see the advantages that accrue from a knowledge of the subject and are inspired with a desire to acquire it. Obviously, in attempting to sell the idea to these, the first step should be to show wherein its value lies.

USES OF THE MICROSCOPE

6. Based upon what is actually being accomplished in various laboratories at the present time, we list the following ways

in which the microscope can be of value to the cast iron foundryman, expressed so as to represent specific problems that arise:

(a) Naturally, the first use of the microscope is to reveal the effect of the various elements present on the structure of iron, and why some make for strength and others for weakness; some for softness and machinability, others for hardness and poor machinability. Such knowledge is fundamental and furnishes the key for solving most other problems.

(b) To show, with two irons of approximately the same composition, why one is strong and the other weak, and to indicate what changes in composition or foundry practice are necessary to make the irons equal.

(c) To determine the amount of variation occurring in regular foundry products from day to day and the probable causes of variation, so that, if necessary, closer control can be maintained.

(d) To make comparison between a given iron and another (possibly a competitor's) which may have proven more satisfactory in service, and to find out what changes are necessary to make the poorer iron equally satisfactory.

(e) To indicate what changes in composition and foundry practice are necessary to produce a product which will conform to customers' requirements for physical characteristics which the present iron will not meet. The time is not far distant when the greater part of the cast iron tonnage of the country will be purchased according to specification requirements higher than can be applied to much of the present output.

(f) To show, with two irons having similar physical characteristics, why one is superior to the other for some special purpose—as, for instance, where wear or machinability are factors.

(g) To determine the variations occurring in the iron in different parts of the same casting, and to indicate whether, in case of trouble due to these variations, it can best be corrected by a change in the com-

position of the iron, a change in the design of the casting or a combination of both.

(h) To determine the cause of porosity, whether shrinkage, gas or dirt, and to suggest means for its elimination.

(i) To point the way to the maximum possibilities in the way of physical characteristics by utilization of every theoretical factor, thus producing the so-called high-test irons and ultimately developing one which will be a close competitor of steel. Such iron will yet be produced.

(j) To determine improvements which can be secured by the use of special alloys such as nickel, chromium, copper, molybdenum, vanadium, etc.

(k) To ascertain by microscopical examination the approximate chemical composition of a given iron—conditions such as form and size of casting, cupola and molding practice, heat treatment, etc., being known. It is not often recognized how accurate such analysis can be, assuming familiarity with a given product and thorough training in metallographic technique.

(l) To preserve, by means of photomicrography, permanent records of various irons for future reference, and to facilitate comparisons between samples.

7. Certainly, with such a range of usefulness, nearly every foundry in the country at times has a need which a practical application of the microscope will meet.

8. The first consideration in the mind of many will naturally be, "Suppose we had the equipment, how are we to use it; would it not be a case of 'all dressed up and nowhere to go?'" This is the need it is hoped can be met to a certain extent by this paper, which must logically confine itself to a consideration of how to interpret what we see.[1]

STRUCTURE FORMS COMMON TO FERROUS METALS

9. The microscope reveals that certain constituents are common to most of the ferrous metals, the group to which cast iron

[1] For the benefit of those unfamiliar with the principles of the microscope and the technique of its use, an appendix has been added to cover these points and also the methods employed in the preparation and etching of the specimens.

belongs. It is these constituents with which we have to do. With the common knowledge (the heritage of all foundrymen) that cast iron is composed of iron, carbon, silicon, manganese, sulphur and phosphorus, as a starting point, let us begin our study.

10. Probably the question most frequently asked by a beginner is, "Can we see each of these elements under the microscope, and the way they are arranged?" The underlying thought back of this question seems to be that if the problem were one of recognizing each element, *per se*, it would be relatively simple, requiring only a knowledge of the appearance of each, for the purpose of microscopical analysis.

Four Major Constituents

11. While this is not the problem at all, actually the problem is, if anything, even more simple, as the number of structures to become familiar with is less than if each element were present in an isolated condition. That is, for most purposes there are only four constituents of cast iron that need be recognized. These are known as *ferrite*, *pearlite*, *cementite* and *graphite*.

12. The identification of each of these four constituents is relatively simple, the major portion of our study being concerned rather with their composition, the conditions which cause their formation and the effect of each on the characteristics of the metal. This involves consideration of the mechanism of solidification of iron and the introduction of other metallurgical terms and conditions which should be thought of as means to an end.

13. In addition to the four essential constituents, there are a few of secondary importance that should be discussed for the benefit of those desiring to go into the subject more deeply.

Solid Solutions

14. Elements such as silicon and manganese form, within the limits of percentages present in cast iron, what is called a solid solution with iron. The nature of a solid solution can be understood by analogy, as for instance, when we dissolve salt or sugar in water the resultant solution does not appear any different to the eye than does pure water. This is a liquid solution, and, in the same way, silicon and manganese added to molten iron dissolve in it to form a homogeneous liquid solution. When this

becomes solid through cooling, it still has every appearance of pure iron, and for this reason is called a solid solution.

15. It is logical, therefore, that the first step in studying a ferrous metal is to become acquainted with the appearance of pure iron (or a solid solution) under the microscope.

Pure Iron

16. Fig. 1 shows the appearance of *Armco* iron, one of the purest forms of iron commercially available. It will be seen that the metal is composed of polyhedral grains, irregular in shape and closely fitted into each other. By various methods it can be proved that each grain is an individual crystal which, if unhindered by pressure of other crystals around it, would have assumed a cubic or octohedral form; hence, they are sometimes referred to as crystals or crystal grains. If silicon or manganese were present, their appearance would not be altered but they would then be solid solution grains.

17. It is desirable that each individual constituent of which a metal is composed be given some name. These grains, being mostly pure iron, accordingly are called *ferrite*, from the Latin word for "iron." This is true regardless of whether they are pure iron or solid solution grains. In cast iron they are always solid solution grains, containing silicon and manganese, and probably other elements as well.

Grain Size Governs Strength

18. Sometimes the ferrite grains are large, sometimes small. Their size is determined by such factors as tapping and pouring temperatures, subsequent working, presence of other alloys, heat treatment, "prenatal" influence, etc. From this it will be evident that grain size is of help in determining the history of the iron, but considerable experience is necessary for this.

19. One rule can be stated, however, which is easy of application: *The finer the grain size, the stronger the metal, other things being equal.*

Effect of Silicon Is Important Consideration

20. In connection with the presence of silicon and manganese, it must be understood that while they are not evident because

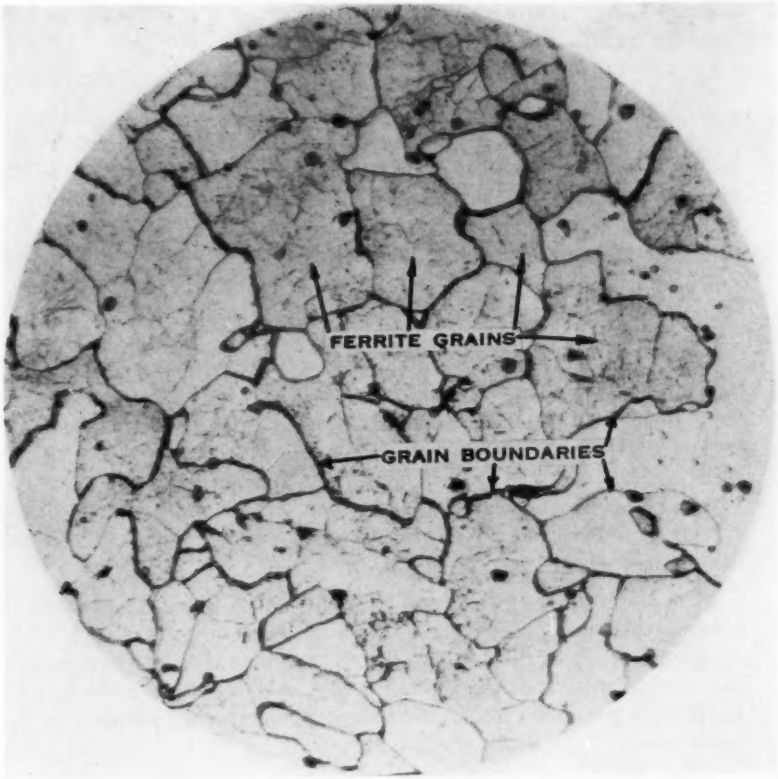

FIG. 1—ARMCO INGOT IRON. X 300. COMPOSED OF GRAINS OF FERRITE ONLY, AS NO CARBON IS PRESENT. SMALL DARK SPOTS ARE IMPURITIES WHICH CANNOT BE ENTIRELY ELIMINATED.

of being in solution in the iron, the *effect* of their presence is something altogether different, which must be considered after we become familiar with the relation existing between iron and carbon. This latter element is unusual in that, while considerable of it will dissolve in molten iron to form a liquid solution, not more than 0.05 per cent can exist in solid solution at normal temperatures. Accordingly, all over this amount must make its presence manifest in some other constituent than ferrite.

Definition of Cast Iron

21. Cast iron has been defined as steel that contains graphite. While the presence of graphite completely changes the physical characteristics of the metal, from a metallurgical standpoint the definition is a good one and opens up a method of studying the effect of carbon that is quite simple.

Mild Steel and Higher Carbon Steel

22. For the time being let us ignore the presence of graphite and start with an iron that contains about 0.20 per cent carbon (which, of course, is called a mild steel). In Fig. 2, showing such a steel, we see the same ferrite grains, but scattered among them are others which have etched dark. As the only difference between this metal and that shown in Fig. 1 is the presence of carbon, it is obvious that the carbon must be associated with the dark constituent.

23. Now let us examine a steel with a still higher carbon content, say, around 0.60 per cent. Fig. 3 is taken from such a steel and, while at first slight it might be thought to show an entirely different structure, closer study reveals that it is similar to the 0.20 per cent carbon steel except for a material increase in the amount of the dark constituent.

24. If we were to examine a large series of steels, properly normalized,[2] with varying carbon content, we would find a direct relation existing between the total area of the dark grains and the carbon percentage, until at about 0.85 per cent carbon the entire mass is composed of dark grains; the ferrite has all disappeared.

[2] Normalizing is a heat treatment for the purpose of allowing every constituent to assume its normal condition; it consists of heating to a little above the critical temperature—which varies with the carbon content, but is around 1600 degs. Fahr.—and allowing to cool at a normal rate in air.

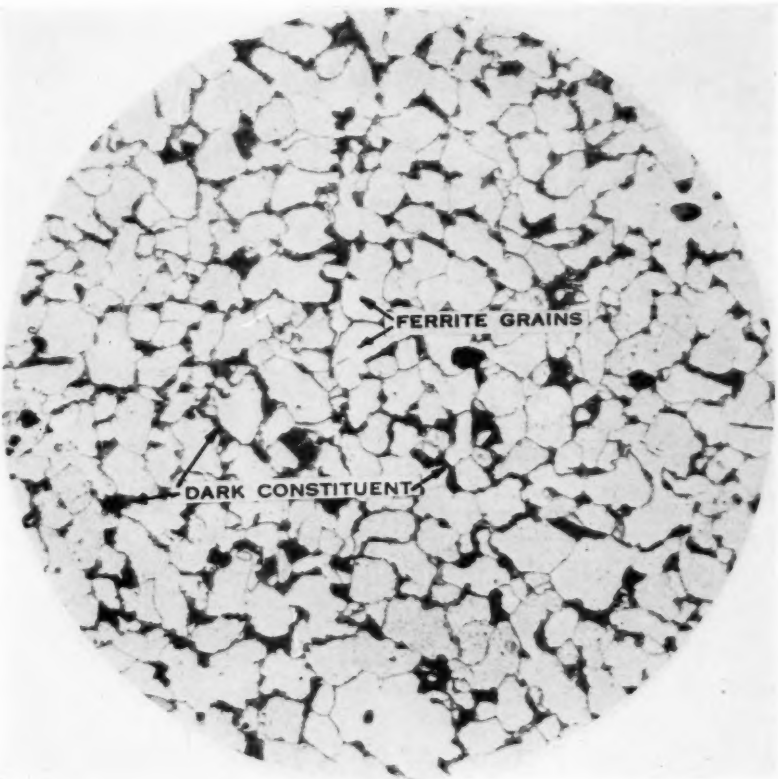

FIG. 2—CARBON STEEL, 0.20 PER CENT CARBON. X 300. INTERSPERSED BETWEEN FERRITE GRAINS ARE DARKLY ETCHING AREAS (PEARLITE), WHERE THE CARBON IS TO BE FOUND. PRACTICALLY NO CARBON IS PRESENT IN FERRITE GRAINS.

FIG. 3—CARBON STEEL, 0.60 PER CENT CARBON. X 300. MOST OF AREA IS TAKEN UP WITH THE DARK CONSTITUENT (PEARLITE), ONLY OCCASIONAL GRAINS OF FERRITE SHOWING.

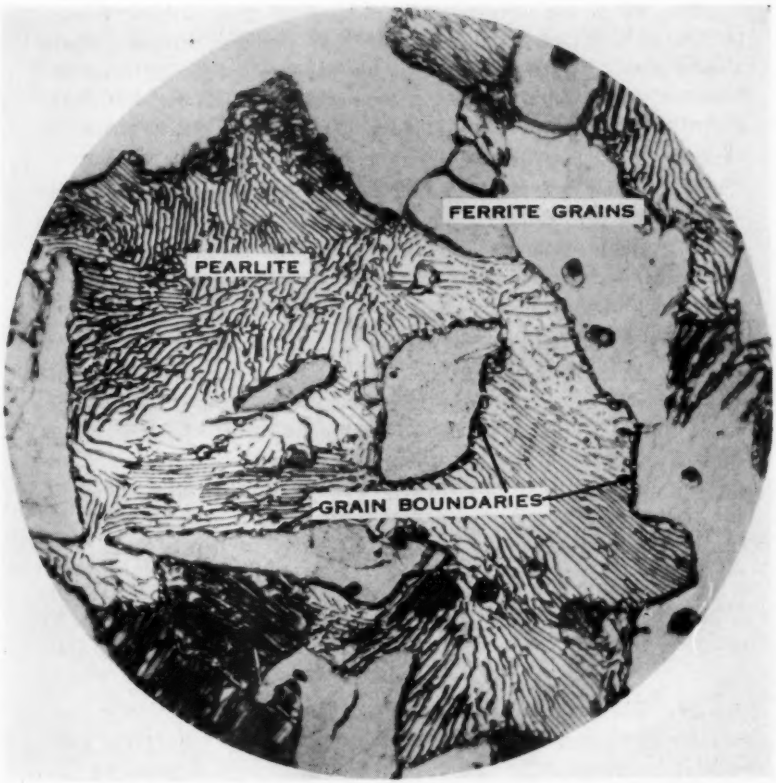

FIG. 4—PEARLITE IN 0.60 PER CENT CARBON STEEL. X 1200. NATURE OF THE DARK CONSTITUENT (PEARLITE) SHOWN AT HIGHER MAGNIFICATION. TYPICAL FINGERPRINT STRUCTURE IS EVIDENT.

Formation of Iron Carbide or Cementite

25. It has been proven that three parts of iron unite with one of carbon to form the chemical compound, iron carbide (chemical symbol, Fe_3C), commonly referred to as cementite, or simply carbide.

26. If we conceive of a solid block of iron carbide, it can be figured out that it must contain 6.67 per cent carbon. Such a solid mass of pure carbide does not exist as a foundry product, however, as it would require a temperature of about 3400 degs. Fahr. to produce it. Also, because it is not stable in the presence of certain other elements, the iron would have to be absolutely pure, that is, not containing even a few thousandths per cent of any element that renders it unstable.

27. Such elements are silicon, nickel, copper, aluminum, etc. However, carbide can and does occur as a microscopical component of ferrous metals, and under such conditions always contains 6.67 per cent carbon.

28. From this it will be evident, as a carbon content of 0.85 per cent is far from sufficient to produce pure carbide but does produce a solid mass of the dark constituent, that the latter cannot be pure carbide. On the other hand, as only iron and carbon are present, if carbide is present at all, the dark constituent ought logically to consist of two components—such carbide as can be produced with the limited amount of carbon present, and pure iron (ferrite) for which no carbon is available. Will the microscope bear us out in this reasoning?

Necessity of Higher Magnification

29. The magnification employed thus far is practically useless for disclosing the nature of the dark grains. For this purpose it is necessary to use a higher power. Fig. 4 gives us the appearance of the dark area at a magnification of 1200 diameters.

30. As will be noted, this substantiates our reasoning, for it discloses the presence of two constituents, alternately laid together with some semblance of regularity, reminding one of a fingerprint. When viewed through the microscope under certain conditions, the structure presents an iridescent, pearly appearance, suggesting the name by which it is metallurgically known, namely, *pearlite*.

PEARLITE

31. As pearlite is one of the most important constituents of both steel and cast iron, it is desirable that we spend a little time considering it. In cast iron especially, the nature and amount of pearlite determine in a large measure the physical characteristics.

32. It has been found that steel, regardless of the carbon content, in cooling slowly through what is known as the critical range adjusts the proportion of its constituents so that the last metal to set to definite form always contains the exact amount of carbon necessary to produce pearlite, *i.e.*, about 0.85 per cent.

33. If the total carbon is less than 0.85 per cent, enough ferrite grains will form first, thus concentrating the carbon in the remaining mixture until it amounts to 0.85 per cent; then pearlite forms. On the other hand, if more than 0.85 per cent carbon is present, instead of ferrite forming first, carbide (cementite) forms, requiring 6.67 per cent carbon to do so, thus impoverishing the balance of the metal until at last only 0.85 per cent carbon remains, which then forms pearlite.

34. From this it will be evident that pearlite always forms at the lowest temperature, hence is called a eutectoid.[3]

Three Structures of Iron-Carbon Mixtures.

35. It will be seen that three different structures are possible in iron-carbon mixtures, as follows: (1) Those with less than 0.85 per cent carbon, consisting of *ferrite* and *pearlite;* (2) those with just about 0.85 per cent, which are *wholly pearlitic;* and (3) those having carbon in excess of 0.85 per cent, which consist of *cementite* and *pearlite.*

Pearlite Structure.

36. The true nature of pearlite is not often recognized, even by steel metallurgists, due to its close approximation to a true eutectic. The latter might be called a mass eutectic, whereas pearlite, because of a peculiarity of iron assuming different crys-

[3] When two metals are melted together, unless they are mutually soluble in each other in all proportions, there is generally some definite proportion where the solidification—and consequently the melting—temperature reaches a minimum which is lower than the melting point of either of the component metals. This particular proportion is called the eutectic mixture. Microscopic examination of the eutectic mixture shows it to be a mechanical mixture, that is, a blending of the two components in a fairly fine state of subdivision, with each maintaining its own identity.

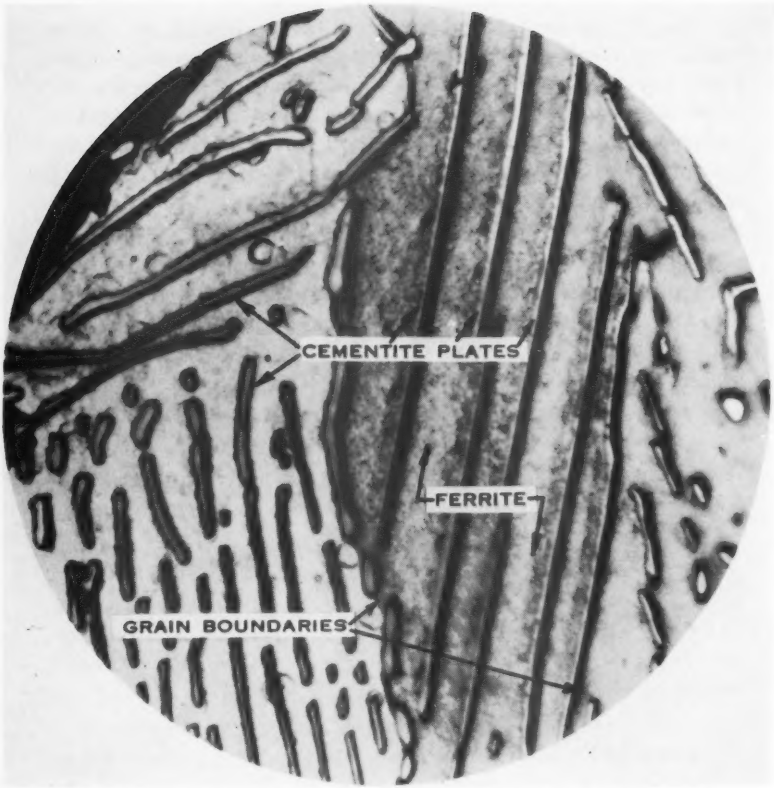

FIG. 5—SHOWING THE NATURE OF PEARLITE. X 3000. PEARLITE IS SEEN TO CONSIST OF PLATES OF IRON CARBIDE (CEMENTITE), OCCUPYING POSITIONS ALONG CRYSTALLOGRAPHIC PLANES OF FERRITE GRAINS, WHICH COMPRISE THE GROUND MASS. PORTIONS OF AT LEAST FOUR GRAINS ARE VISIBLE.

tal or allotrophic forms at different temperatures (called *alpha* and *gamma* irons), is not a mass eutectic but an individual grain eutectic. Each grain of pearlite should be conceived of as a ferrite grain containing cementite in which the latter has been forced to positions along crystallographic planes of weakness.

37. In most cases a pearlite area consists of several individual grains. This point will be understood by examining Fig. 5, which shows, at a magnification of 3000 diameters,[4] the cementite definitely oriented in portions of four grains.

Effect on Physical Properties.

38. The comparatively wide spacing of the cementite plates in this iron also should be noted, as it makes the next point easy of comprehension, that is, that pearlite may vary in different irons from extremely fine to very coarse, and the physical characteristics of the iron will vary accordingly. Not only the fineness of the pearlite may vary but, as in the case of pure ferrite grains, the pearlite grain size also may vary; and this, too, is a factor in determining the nature of the iron.

39. While the iron shown in Fig. 5 has unusually coarse pearlite, it is typical of much that is being turned out in foundries where no check is kept on the quality of the product, especially where high silicon and heavy sections are combined.

40. A more desirable pearlite is shown in Fig. 6, which shows a plain pearlitic iron at 2000 diameters magnification, or 2000x, as it usually is written. The grain size also is fine in this iron, the grain boundaries being readily visible, or at least apparent from the change in direction of the laminations. In order to facilitate grain-size determination and to emphasize what has been stated with regard to the nature of pearlite, Fig. 7, the same micrograph, is shown with the grain boundaries marked off more clearly.

41. An iron with larger grain-size but finer laminations is shown in Fig. 8 (2000x). Fig. 9, at the same magnification, shows an extremely fine pearlite in a brake-drum iron, while Fig. 10 shows a pearlite no longer of parallel plates but more or less disorganized and in a fine state of subdivision.

[4] It is not possible with ordinary metallurgical microscopes to obtain this high magnification, nor is it necessary for anything but research purposes. It is employed for some of the micrographs in this paper in order to simplify an understanding of some of the structures under discussion.

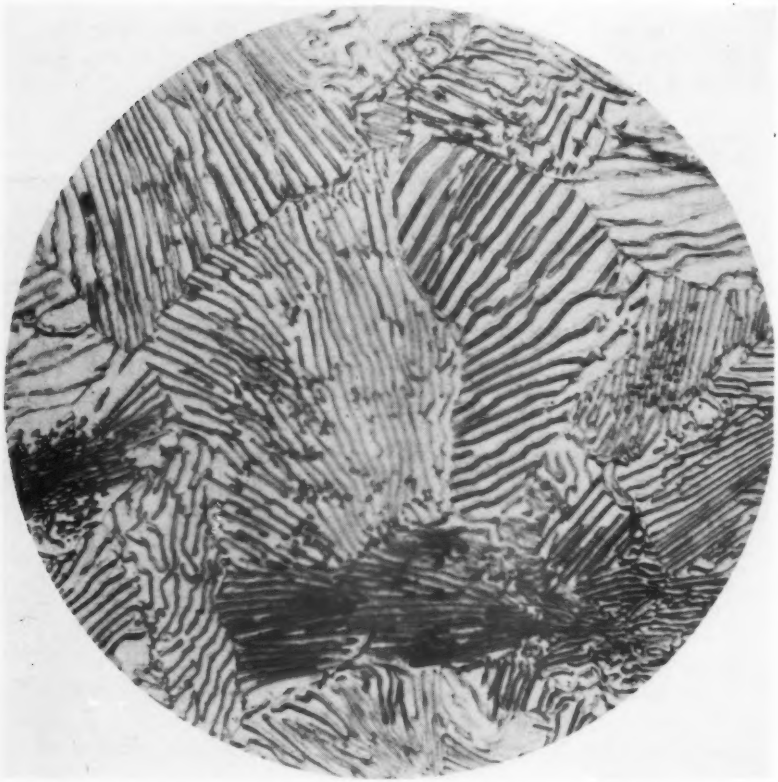

FIG. 6—PEARLITE GRAINS IN PEARLITIC IRON. X 2000. MEDIUM FINE LAMINATIONS OF CEMENTITE IN FINE GRAINS, UNIFORMLY PEARLITIC, ARE PRESENT IN THIS IRON.

FIG. 7—SAME MICROGRAPH AS FIG. 6, WITH GRAIN BOUNDARIES MARKED OFF TO SHOW AVERAGE SIZE AND NATURE OF THE GRAINS.

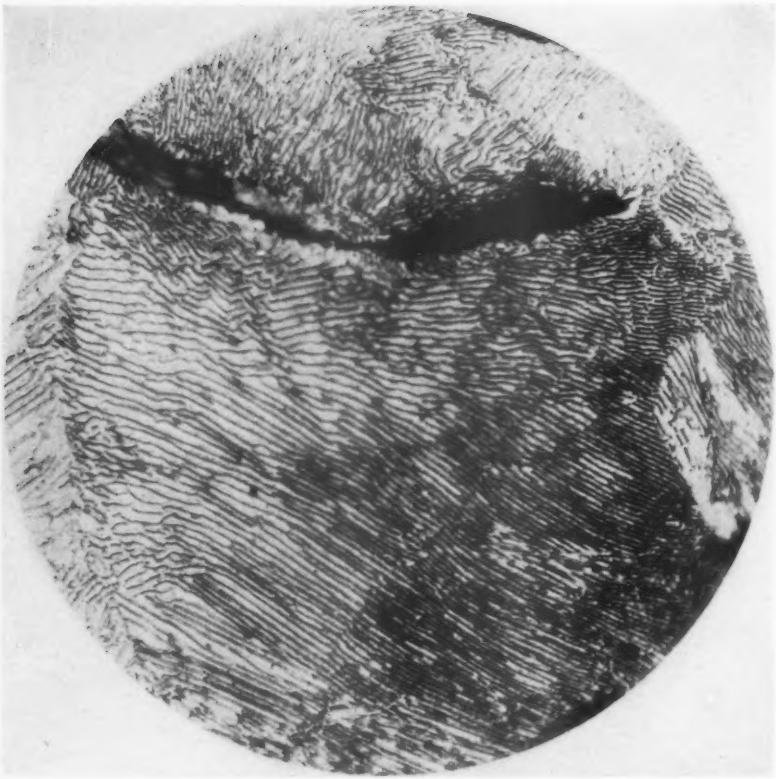

FIG. 8—LARGE-GRAIN PEARLITE. X 2000. THIS IRON HAS FINER LAMINATIONS THAN THAT SHOWN IN FIG. 6, BUT GRAIN SIZE IS MUCH LARGER.

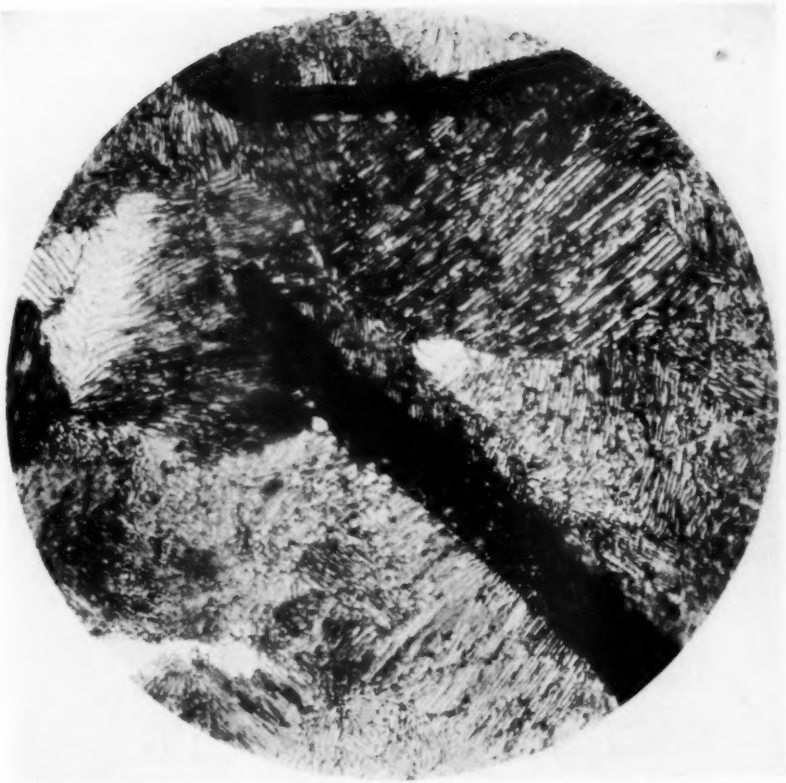

FIG. 9—VERY FINE PEARLITE. X 2000. LAMINATIONS OF THE PEARLITE AND THE GRAIN SIZE ARE BOTH VERY FINE IN THIS IRON.

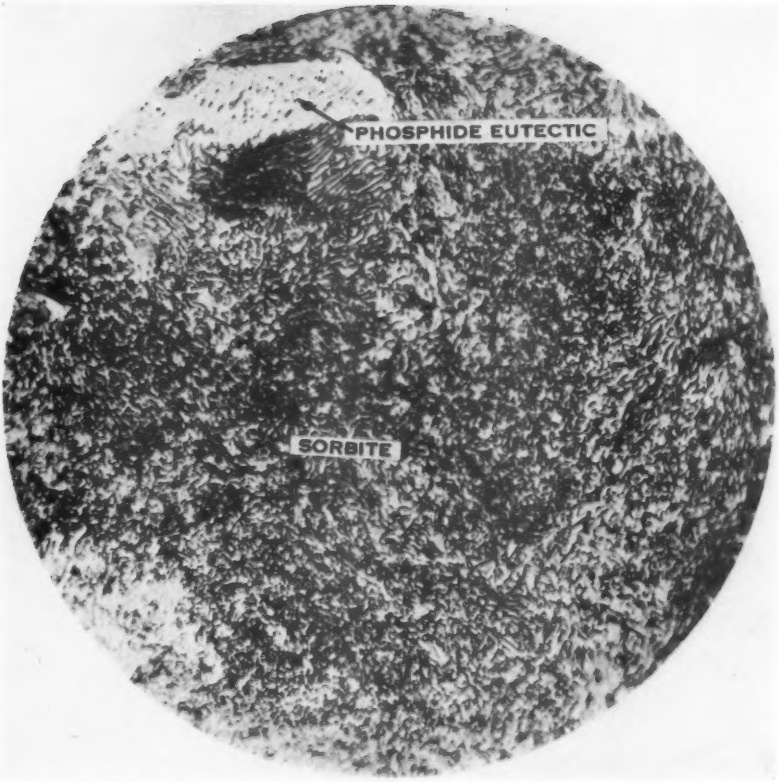

FIG. 10—SORBITIC CAST IRON. X 2000. PEARLITE OF THIS IRON IS SO FINE AND BROKEN UP THAT IT IS CALLED BY DIFFERENT NAME: SORBITE. TRUE PEARLITE NATURE IS EVIDENT IN SOME PLACES.

Sorbite Structure.

42. Careful examination of Fig. 10 shows, however, that this structure still is similar to pearlite in that it is a mixture of cementite in ferrite; but, as the magnification usually employed for metallurgical purposes does not reveal its true pearlitic nature, it is generally called *sorbite*. For simplicity, let us think of it as the finest possible pearlite.

Spheroidized Pearlite.

43. There is yet another form of pearlite in which the cementite is in globular masses instead of plates; but with the basic nature of pearlite in mind, it is not confusing, even to a beginner in metallurgical science. It is known as spheroidized pearlite (or cementite) and appears as shown in Fig. 11, where all stages from plates to globules may be seen.

Effects of Pearlite Variations.

44. The conditions responsible for variations in the nature of pearlite will become evident as we take up other phases of the subject. However, based on the results of a large number of tests and the correlation of research data, certain general statements can be made at this time regarding the effect of these variations, as follows:

(a) The strength of cast iron increases as the amount of pearlite increases.

(b) The finer the pearlite, the stronger the iron.

(c) Small grain size is conducive to increased strength.

(d) Brinell hardness increases with increase in fineness and amount of pearlite, proceeding from a ferritic to pearlitic condition. (If freedom from free cementite is assured, this method of test can be used as a check on the nature of the iron after coordinating the hardness and microstructure for a given product.)

(e) Increase in fineness and amount of pearlite and decrease in grain size result in some increase in the toughness noticeable in machining operations, but produce a corresponding smoother finish and never re-

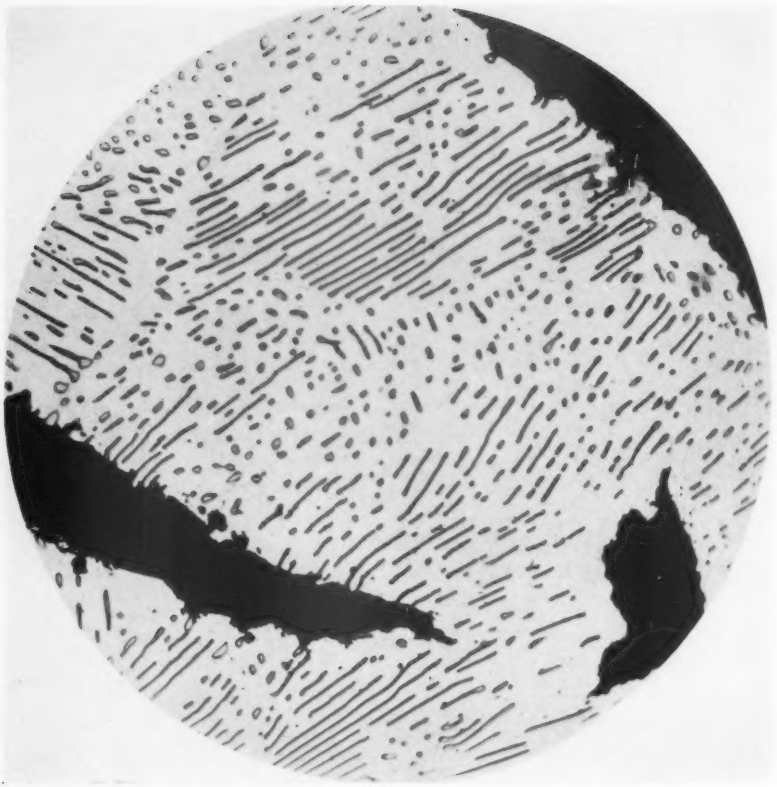

FIG. 11—SPHEROIDIZED PEARLITE. X 2000. SOMETIMES CEMENTITE IS IN GLOBULAR FORM INSTEAD OF IN PLATES. RELATION BETWEEN THE TWO FORMS IS EVIDENT HERE. ALL DEGREES OF FINENESS CAN OCCUR, FROM VERY COARSE AS IN THIS SAMPLE TO SORBITE OF FIG. 10.

sult in a metal which is unsatisfactory from a machining standpoint.

45. The above statements must be understood to be qualified by the phrase "other conditions being equal," for the large number of factors and elements affecting cast iron make it by far the most complex metal with which metallurgists have to deal, and the influence of one factor may be completely offset or greatly modified by some other.

GRAPHITIC CARBON

46. Thus far we have only been considering — insofar as cast iron is concerned—that portion of the total carbon which the chemist reports as "combined carbon" and which for most purposes obviously should not exceed 0.85 per cent, as at this value the iron should be wholly pearlitic. (The effect of silicon and manganese in modifying this figure will be taken up later in this paper.)

47. There yet remains the bulk of the carbon, probably amounting to from 2.5 to 3 per cent, to account for. Every gray iron foundryman knows that this must exist as graphite, but in our microscopical study we must know more than that. We must become familiar with the causes of its formation, modes of occurrence and the reasons for its large influence on the physical characteristics of the iron.

48. It is better to begin a study of graphitic carbon from the standpoint of what a normal iron-carbon mixture would be without the presence of other elements; then the mechanism of graphite precipitation can be more readily traced and the methods for its control better comprehended. With approximately 3.5 per cent carbon ordinarily present in cast iron, there still is not sufficient to form pure iron carbide requiring 6.67 per cent, hence (whether or not graphite is present), some ferrite must be present as one component. Let us locate this ferrite, as well as the carbide (cementite).

49. There exists a true eutectic at 4.3 per cent carbon which corresponds somewhat to the eutectoid point at 0.85 per cent, but it will not be necessary to devote much time to its consideration as it does not play an appreciable part in the nature of gray iron. When dealing with a silicon-free mixture, however, it

must be reckoned with if we are to understand all the mechanism of solidification.

State of Carbon in Iron.

Formation of Crystals with Iron of 1.7 Per Cent Carbon or Less.

50. In the molten state iron and carbon are in homogeneous liquid solution. We are interested in what happens as it cools. Perhaps we should start with a mixture containing not more than 1.7 per cent carbon, which is the limit of solubility of carbon in iron at the temperature of solidification. In Fig. 12, *A*, *B*, *C* and *D* visualize what takes place.

51. Iron, like all elements, consists of atoms. In the molten state they are free to move, loosely arranged and possess no regularity of position. This condition can be likened to the arrangement of dice in Fig. 12-*A*, each dice representing an iron atom. We must imagine that carbon atoms also are present, but so small compared to the iron atoms that they are not visible.

52. As cooling takes place, some of the atoms begin to arrange into groups, as shown in Fig 12-*B*. Once formed, these groups continue to grow by adding other atoms as the temperature falls, as illustrated by Fig. 12-*C*.

53. The condition of the iron as represented by *B* and *C* of Fig. 12 is that known as "mushy"—the dice not yet arranged representing liquid iron and the arranged groups, solid iron crystals (holding carbon in solution). Finally a state of complete solidity is reached, as pictured in Fig. 12-*D*. If it were possible for us to polish and etch the metal in this last condition, at a temperature of about 2000 degs. Fahr., it would appear like the pure iron shown in Fig. 1.

Formation on Cooling of Iron with 3.5 Per Cent Carbon, Silicon Free.

54. Leaving this mixture for the time being, and following through one with 3.5 per cent carbon but silicon free (*i.e.*, a white iron), we find that at a somewhat lower temperature than in the former case (about 2200 degs. Fahr.) crystals begin to form, in a similar manner to the 1.7 per cent mixture. It is found that the crystals are identical in nature also, never containing more than 1.7 per cent carbon regardless of the amount present in the mixture.

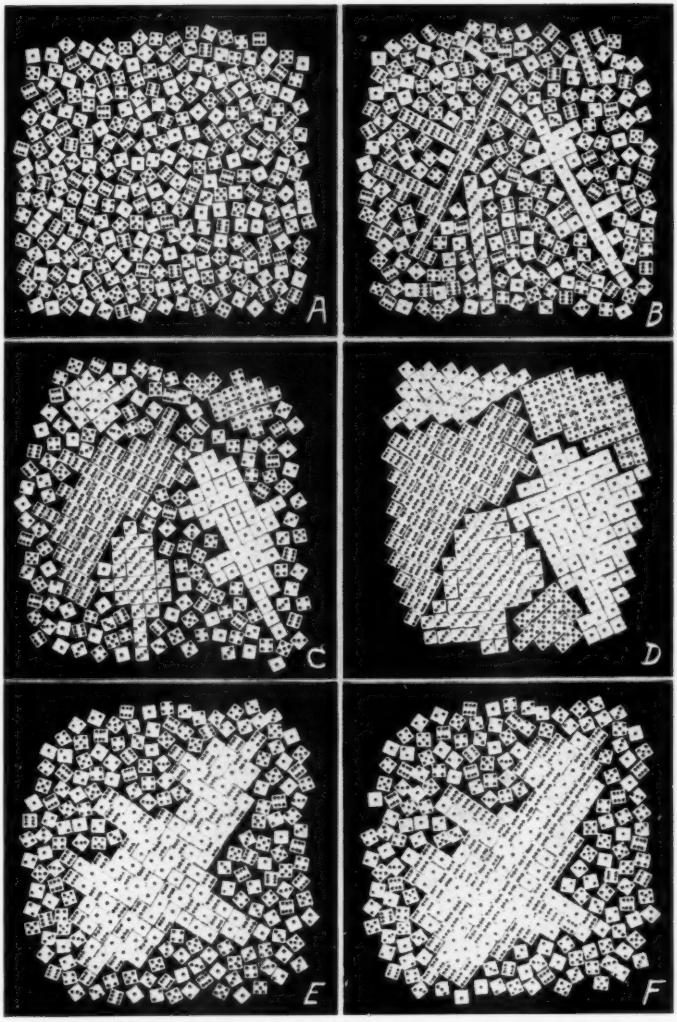

FIG. 12—SCHEMATIC REPRESENTATIONS OF CHANGES IN METAL STRUCTURE.

A: ATOMIC CONDITION OF MOLTEN METAL.

B: BEGINNING OF SOLIDIFICATION, DENDRITE CRYSTALS FORMING IN THE MOLTEN MASS.

C: CRYSTAL GROWTH FURTHER ADVANCED AND SOLIDIFICATION NEARLY COMPLETE.

D: SOLIDIFICATION COMPLETE.

E: NATURE OF AUSTENITE DENDRITE IN MATRIX OF EUTECTIC. CARBON (OR CARBIDE) IS IRREGULARLY DISPOSED THROUGHOUT AUSTENITE.

F: ONE-SPOT DICE, HERE SEEN REGULARLY ARRANGED WITHIN THE DENDRITE, REPRESENT THE CARBON (AS IRON CARBIDE) IN CONDITION IT IS IN, IN PEARLITE. *E* (AUSTENITE) AND *F* (PEARLITE) ARE SIMILAR EXCEPT FOR ARRANGEMENT OF CARBON ATOMS.

Austenite Dendrites and Ledeburite.

55. These crystals belong to the cubic system of crystallization and the name *austenite* has been given to them.

56. Growth in cubic crystals takes place in three directions at right angles to each other, and the tendency is to form a cube. (Just as we might pile the dice together in three ways, only two of which are shown in the figures, as they are all in the same plane.) At first however, they are only skeleton crystals having a pine-tree appearance and for this reason are called *dendrites*, from the Greek word for "tree." These austenite dendrites are forming all the time that the temperature is falling, thus taking out of the solution more iron than carbon, resulting in an increased concentration of the latter in the molten mass until it finally reaches 4.3 per cent.

57. At this stage the entire mass solidifies as the eutectic, which in this case consists of fine austenite globules in a matrix of cementite, to which the name *ledeburite* has been given.

58. The dice may help to visualize the appearance at this stage. Fig. 12-*E* represents a dendritic crystal of austenite in a matrix which must now be thought of as solid, the ledeburite eutectic. Let us imagine the 6-spot dice in the crystal to represent iron atoms and the 1-spots to be carbon atoms (or, preferably, groups of Fe_3C molecules). At the temperature of solidification they are mixed up without there being any segregation of either.

59. Leaving the dice for a moment, let us take a look at a white iron such as the dice represent, which has cooled to normal temperature, and we will see what is shown in Fig. 13. It gives a good idea of the pine-tree structure but there does not seem to be much structure in the matrix. This is because in the case of a very rapid fall of temperature through the solidification range, as happened with this sample, resolution of the eutectic is inhibited. Fig. 14 shows an iron in which the ledeburite eutectic has developed properly.

60. We have been referring to the dendritic crystals during solidification as austenite, but examining either of the irons shown in Figs. 13 or 14 with high magnification, as in Fig. 15, reveals that after all they composed of our old friend *pearlite*. What

FIG. 13—WHITE IRON. X 175. SHOWING PINE-TREE FORM OF DENDRITES FROM WHICH THE NAME "DENDRITES" IS DERIVED.

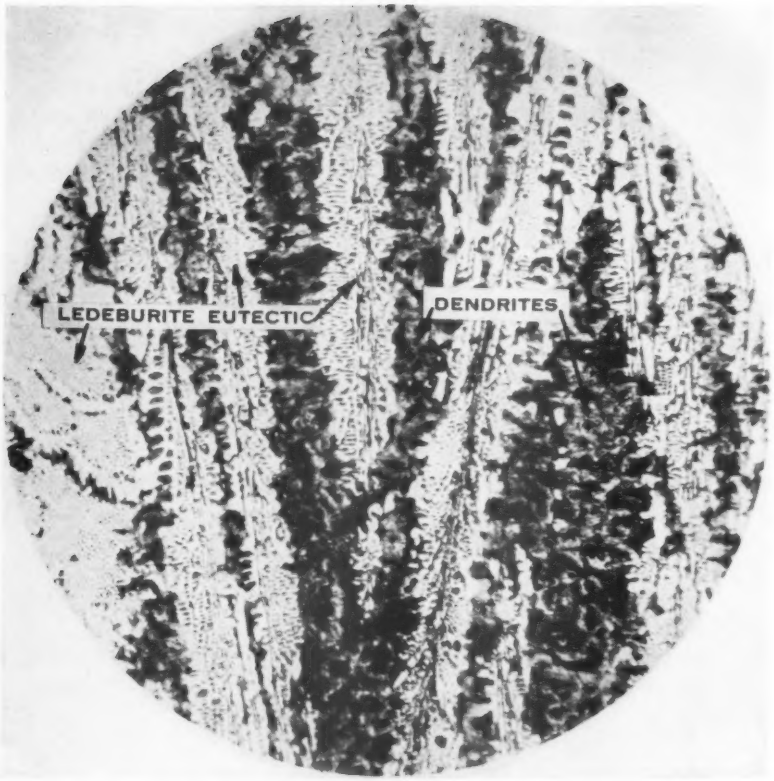

FIG. 14—CHILLED IRON. X 200. SHOWING PRIMARY DENDRITES AND THE EUTECTIC STRUCTURE KNOWN AS LEDEBURITE.

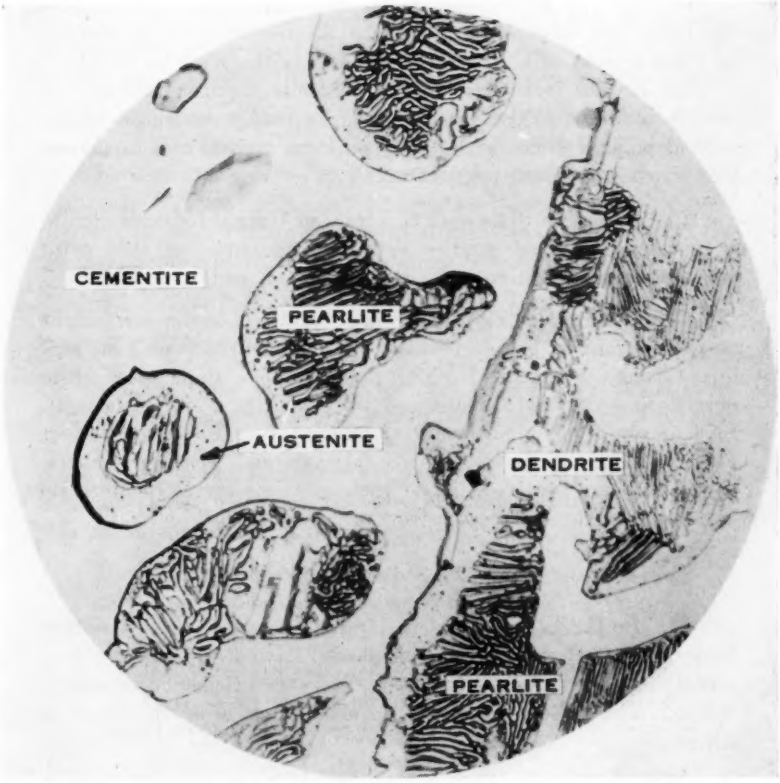

FIG. 15—CHILLED IRON. X 2000. AT HIGH MAGNIFICATION THE DENDRITES ARE SHOWN TO CONSIST OF PEARLITE. IN THIS IRON, DECOMPOSITION OF ORIGINAL AUSTENITE TO PEARLITE IS NOT ALTOGETHER COMPLETE.

happens in this: When austenite cools to about 1300 degs. Fahr.[5] the iron changes to a different form (*alpha* iron), throwing out the carbon as iron carbide, exactly as in the case of steel; thus forming pearlite. We can rearrange the dice of Fig. 12-*E* to show this.

61. In Fig. 12-*F* there are the same sixes and ones but now the latter are aligned in a definite manner within the crystal. In other words, while the external form is the same in *E* and *F* of Fig. 12, the former represents austenite, or iron and carbon as they occur at 2000 degs. Fahr. (or any temperature above the critical point), while the latter is pearlite, or iron and carbon as they occur at normal temperatures.

62. Thus, it will be seen that we can largely forget austenite in our microscopical studies and concern ourselves only with pearlite, austenite being only a means to an end.

63. Before leaving this subject, however, reference might be made again to Fig. 15, which is from an iron cooled so rapidly through the critical range that complete decomposition to pearlite has not taken place and some austenite still is present. Such a condition is primarily of interest to chilled iron foundries, where problems relating to hardness and wearing qualities of the chill are involved, but at the same time serves to illustrate how complex the entire cast iron problem can be.

Where Does Graphite Form?

64. So far we have seen nothing of graphite. At what stage does it manifest itself? We purposely started out with an iron containing only carbon—that is, free of other elements, especially silicon. The reason for this is to make more clear the effect of silicon.

65. As we have brought the iron down to normal temperature, yet have seen no graphite, let us state the evident conclusion derived in this way: *If no silicon or other graphitizing element is present, there will be no graphite.*[6]

66. Even very slow cooling or prolonged heat treatment can

[5] It then contains only 0.85 per cent carbon, as all in excess of this amount has been thrown out while cooling to this temperature.

[6] This is assuming the complete absence of graphitic nuclei, as the affinity of carbon atoms for carbon masses at temperatures below solidification is sufficient to render carbide unstable.

only result in the development of a perfect eutectic (ledeburite) and complete transformation of austenite to pearlite. Such an iron would be extremely hard, brittle and unmachinable by ordinary methods and useless even for the production of malleable iron. On the other hand it is largely hypothetical, as it is difficult to produce, even in the laboratory. However, to all intents and purposes the effect is the same if only a little silicon be present, the principal difference being the occasional occurrence of graphite and the possibility of softening by continued heat treatment.

67. This brings us to the consideration of the effect of silicon within the percentages ordinarily present in gray iron. In the language which every foundryman knows, silicon functions as a softener. The softening is accomplished through the decomposition of the free cementite and eventually the cementite of the pearlite, resulting in the liberation of free carbon atoms, which unite to form graphite.

Factors in Graphite Precipitation.

68. Numerous theories have been proposed to explain the exact mechanism of graphite precipitation, but as metallurgists have not as yet come to an agreement, the present paper is no place to enter the controversy. However, we can state certain facts associated with graphite precipitation which have a direct bearing on the production of high-quality irons, as follows:

(a) Precipitation of graphite is dependent upon the silicon content, the carbon content and the rate of cooling through a certain temperature range.

(b) With a given carbon content and rate of cooling, increase in silicon means increased graphite and larger graphite flakes.

(c) For a given carbon and silicon content, slower cooling results in increased graphite, generally in larger flakes.

(d) With a fixed silicon and cooling rate, decrease in the total carbon results in less graphite, usually in smaller flakes.

(e) Graphite precipitation is not limited to the amount of carbon present in excess of the eutectoid

composition (0.85 per cent), but, with ample silicon or a very slow rate of cooling, it can continue until practically no combined carbon is present.

(f) Graphitization is aided by the presence of graphite nuclei, *i.e.*, small groups of carbon atoms persisting through the molten state in crystallographic arrangement. High melting temperature tends to destroy these nuclei.

Graphite Variation in Cast Iron

69. It may be that some do not appreciate the extent to which graphite can vary in different irons and that examination of a few samples under the microscope is warranted. For this purpose it is not necessary to etch a specimen, a careful polishing being all that is required, as the contrast between the black graphite and bright metal is greater than after etching and the details of other structures do not confuse.

Graphite in Fairly Good Quality Iron.

70. Fig. 16 (100x) shows the graphite of a fairly good quality iron, the sample being taken from the center of a standard test bar. We might call this a typical graphite; that from the outer portion of the bar would be somewhat finer, due to a faster rate of cooling, while if the diameter of the bar were greater, the graphite in the center would be coarser, due to slower cooling.

71. In actual castings the same conditions apply, so that we would expect coarse graphite in a heavy, slow-cooling section and fine graphite in a light section. As there is no appreciable strength in graphite, in visualizing its effect on the strength of a casting it is a good plan to think of each flake as a void, such as a crack or cavity.

Graphite in Weak Iron.

72. Fig. 17, at the same magnification, shows the graphite in the gray iron portion of a mine car wheel. It does not require an expert to guess that this iron is inherently weaker than the previous sample, insofar as the graphite is concerned. Yet with practically the same total carbon, this latter, because of

being a chilling iron, has but about one-half the silicon of the other.

73. Therefore, the potent factor in this case has been the rate of cooling, which is obvious, as a 150-lb. casting cannot cool as rapidly as a test bar. Had the iron in the wheel been cast into a test bar, the result would have been a white iron with practically no graphite.

74. With this principle operating in the case of castings with both light and heavy sections, it is conceivable that some part of a casting might be made stronger by being made lighter, due to the weakening effect of coarse graphite.

Improvement of Graphite Structure

75. Stated another way, so as to make a practical application of the microscope, suppose we have taken a contract for a certain casting. Shortly after delivery starts we are advised that the castings are failing in service, whereas our competitor's are standing up. Forgetting the old-line "bunk" about perfect and sound castings, seventy-five years in the business, complete satisfaction to other customers, mishandling after leaving our hands, unusual service conditions, etc., etc., we secure a sample of the competitor's casting and make microscopical comparison with ours.

76. The competitor's casting, let us suppose, has a graphite similar to that of Fig. 16; ours appears like Fig. 17. What are we to do? Probably one or more of the following solutions will take care of the situation:

(1) Lower the silicon (or total of graphitizing alloys).

(2) Lower the total carbon by the use of more steel scrap.

(3) Destroy more graphite nuclei by a higher melting temperature (steel addition will help here also).

(4) Substitution of other graphitizing allows (*e.g.*, nickel) tending to give finer graphite, for a portion of the silicon.

(5) Use of alloys (*e.g.*, chromium) tending to neutralize silicon and prevent excessive graphitization.

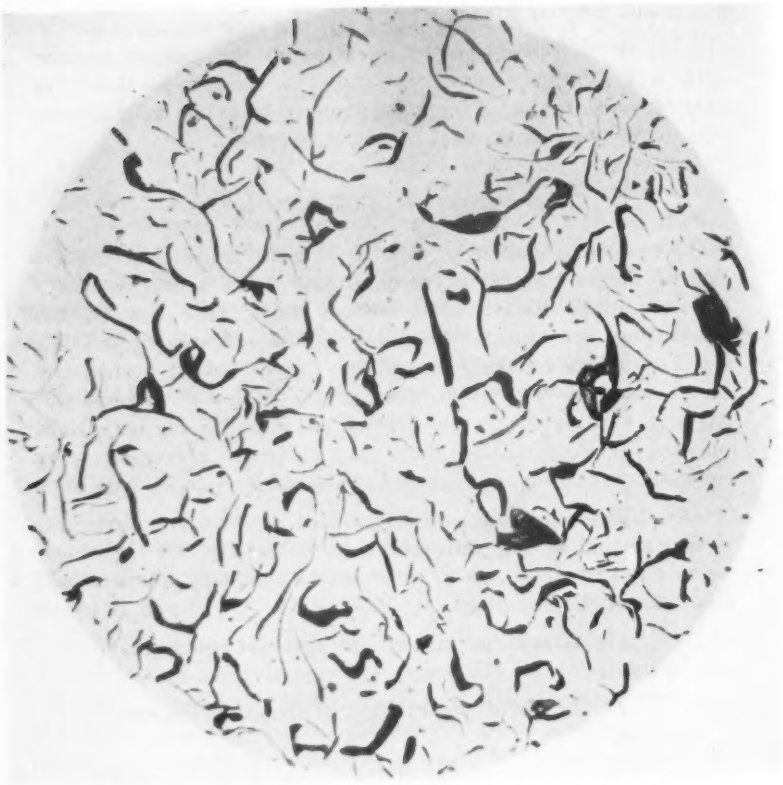

FIG. 16—NORMAL GRAPHITE IN CAST IRON. X 100. APPEARANCE OF TYPICAL GRAPHITE IN UNETCHED SPECIMEN OF CAST IRON.

FIG. 17—COARSE GRAPHITE IN CAST IRON. X 100. EXAMPLE OF COARSE UNDESIRABLE GRAPHITE, CAUSED BY EXCESSIVE SILICON FOR RATE OF COOLING OF THE CASTING.

(These latter possibilities will come up for discussion later.)

77. Also, while we are at it, and if possible without getting into other difficulties, we should go one step farther and turn out castings with graphite still finer than that in our competitor's casting.

Graphite in High-Quality Plain Iron.

78. Logically, the next question is: "How fine can we get the graphite for commercial purposes?" By making the most of every factor entering into graphite precipitation, we obtain the result shown in Fig. 18—a pearlitic iron, being, in fact, the same as that from which Fig. 6 was taken.

79. This is, however, a plain iron, nickel and chromium not being present. The total carbon is reduced, by the use of a high percentage of steel scrap, to 2.85 per cent. Graphite nuclei are destroyed by superheating, also brought about by the use of steel. The silicon content and rate of cooling are adjusted so that the resultant combined carbon is 0.90 per cent, thus bringing the graphite under 2 per cent.

Graphite in Nickel Cast Iron.

80. The use of nickel and its influence on the microstructure will be brought up later, but its effect on the graphite can be illustrated at this time by Fig. 19, which was taken from a test bar of nickel-alloy cylinder iron and shows an unusually fine graphite. When castings are produced in regular practice having a graphite distribution equal to that shown in these last two views (Figs. 18 and 19), cast iron will come into its own once more.

Effect of Silicon on Pearlite

81. While silicon is generally considered with reference to its effect on graphite formation, its influence on the nature of the pearlite must not be overlooked. If only its action would cease when the combined carbon reaches a value of about 0.85 per cent, the whole story of cast iron would be different. We could then rest assured of a pearlitic iron, regardless of the nature of the graphite.

82. The action of silicon in decomposing the cementite of the pearlite continues as long as the temperature is maintained above a certain point (about 1350 degs. Fahr.), and the action is more rapid at any given temperature, in proportion to the increase in silicon content.

83. Fig. 20 (300x) shows an iron where such continued action has taken place. The increase in graphite is obvious, also that this is at the expense of the cementite in the adjacent grains, which are no longer pearlitic but pure ferrite, similar to those shown in Fig. 1.

84. Looking at this iron at high magnification so as to compare its appearance with those previously examined (Figs. 6 to 11, inclusive), we get the appearance shown in Fig. 21 (2000x). The yield point of a pure iron would be around 22,000 lbs. per sq. in., while that of an 0.85 per cent carbon steel would be several times as much. Hence, it is evident that, apart from the effect of the graphite, the strength of the iron shown in Fig. 20 would be abnormally low, probably about 12,000 lbs. per sq. in.

85. As soon as the combined carbon is lowered appreciably below the eutectoid percentage, it becomes evident not only in the presence of free ferrite but also in the increasing coarseness of such pearlite as remains. This makes it comparatively easy to determine by microscopical examination, after a little experience, the approximate percentage of combined carbon in hypo-eutectoid irons.

86. If the combined carbon is higher than the amount necessary to form a wholly-pearlitic iron, trouble from hard spots, chilled corners, mottling, etc., may be expected. This is because of the presence of free cementite. Therefore, familiarity with the method of its formation in the presence of silicon, and ability to recognize it under the microscope, are desirable.

Silicon and Rates of Cooling

87. To obtain this knowledge in the simplest way, let us tabulate the three conditions previously stressed which, taken together, determine the final nature of the iron. These are:

(a) With no silicon present, the iron will be white under all conditions of cooling.

(b) With sufficient silicon, the iron will be gray under all conditions of cooling.

(c) Between these extremes are mixtures that are either white or gray, depending upon the silicon content and the rate of cooling. That is, for every silicon content there is a critical rate of cooling which, if exceeded, will produce some chilled iron (free cementite); and for every fixed rate of cooling, there is a critical silicon content, and further reduction will result in some chilled iron.

Chilled Iron.

88. It is this third condition which is taken advantage of in the production of chilled castings such as car wheels, rolls, etc. It is not within the scope of this paper to enter into a detailed discussion of chilled iron, but some mention of it is desirable not only because through it we obtain a better understanding of what happens when free cementite develops in gray iron, but also because a superficial knowledge of chilled iron will broaden the gray iron foundryman's understanding of the metallurgy of cast iron.

89. Chilled iron, after all, differs from gray iron only in the careful adjustment that is made between the silicon content and the rate of cooling. It is unquestionably the most difficult of irons to control, as the balance between these two factors must be held sufficiently close to assure gray iron in the non-chilled portion and white iron in the chill. Just as with gray iron, if the silicon is too low, there will be free carbide in the non-chilled portion, rendering it brittle and difficult to machine.

90. Let us try to visualize the reason for this. In addition to the effect of silicon on graphite formation, the decomposition of cementite and the nature of pearlite, at an earlier stage it also has an effect other than that where graphite precipitation begins. Silicon-free iron-carbon solidification has been illustrated in Fig. 12, *A* to *F*, indicating that in this case dendritic growth proceeds to a definite point and stops, regardless of the rate of cooling. With silicon present, it is possible for growth of the dendrites to continue until the entire matrix is transformed into dendritic material.

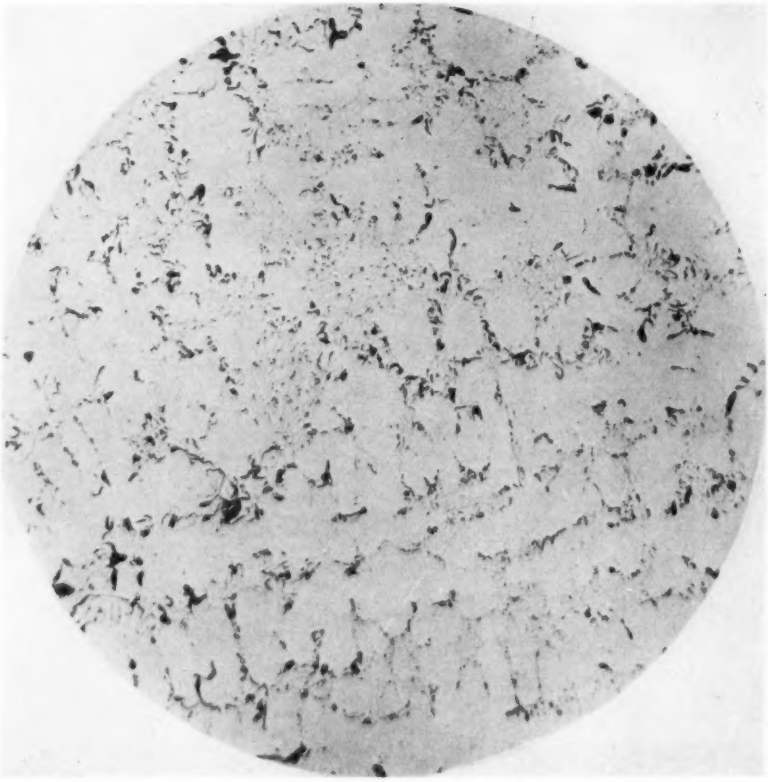

FIG. 18—EXTREMELY FINE GRAPHITE. X 100. LOW-CARBON, HIGH-TEMPERATURE IRON WITH SECONDARY GRAPHITE IN REMARKABLY FINE DISPERSION.

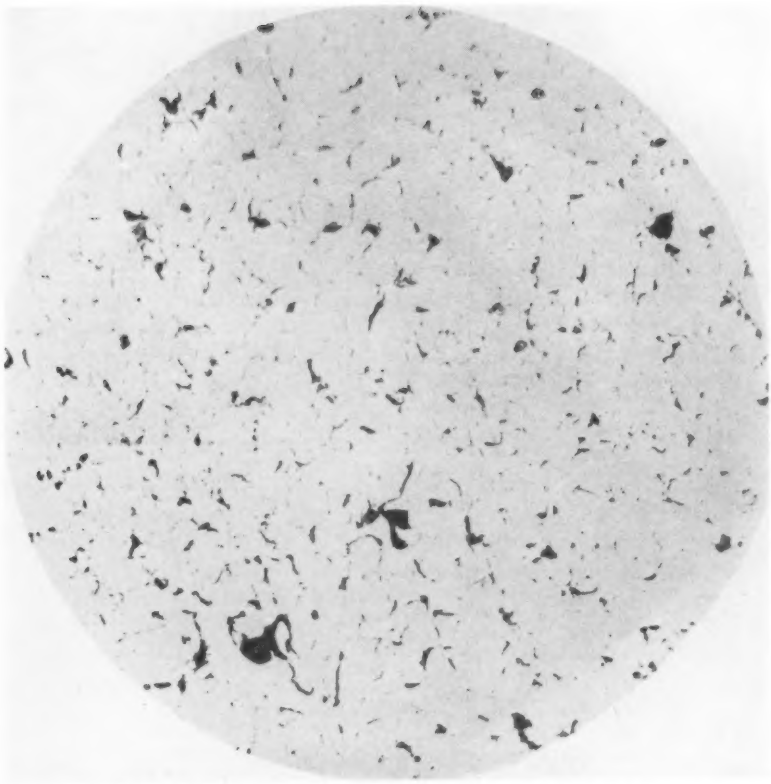

FIG. 19—FINE GRAPHITE IN NICKEL ALLOY CAST IRON. X 100. TYPE OF GRAPHITE GREATLY TO BE DESIRED FOR HIGH-QUALITY IRONS.

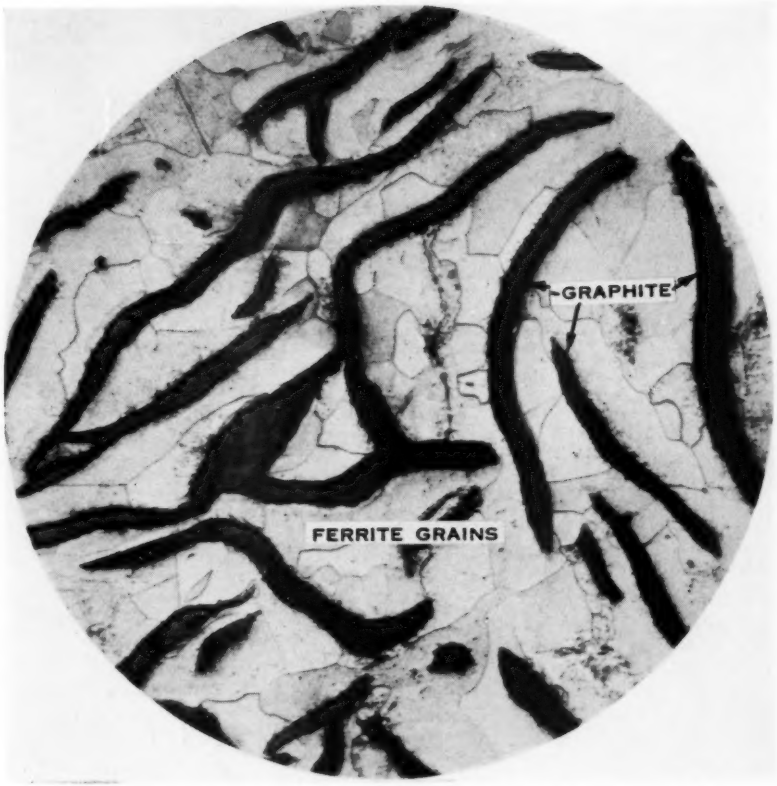

FIG. 20—FERRITIC CAST IRON. X 300. TOO MUCH SILICON FOR COOLING RATE HAS THROWN ALL THE CARBON OUT AS GRAPHITE, AND ONLY FERRITE REMAINS. POOREST POSSIBLE IRON INSOFAR AS STRENGTH IS CONCERNED.

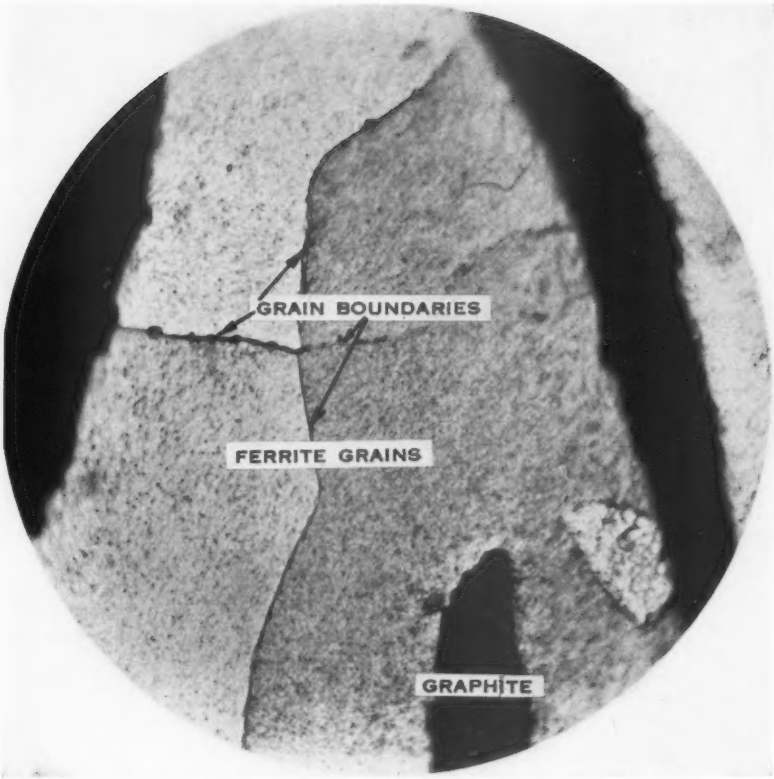

FIG. 21—FERRITIC CAST IRON. X 2000. SAME IRON AS SHOWN IN FIG. 20, AT HIGH MAGNIFICATION FOR COMPARISON WITH PEARLITE VIEWS, FIGS. 6 TO 11.

Dendrites in Presence of Silicon.

91. This is illustrated in Fig. 22, which shows, diagrammatically, four stages in the development of the dendrites in the presence of silicon. The first corresponds to the dice shown in Fig. 12-*A*. In the succeeding stages growth has progressed until in the last it is complete.

92. When once formed, the dendrites continue to grow as

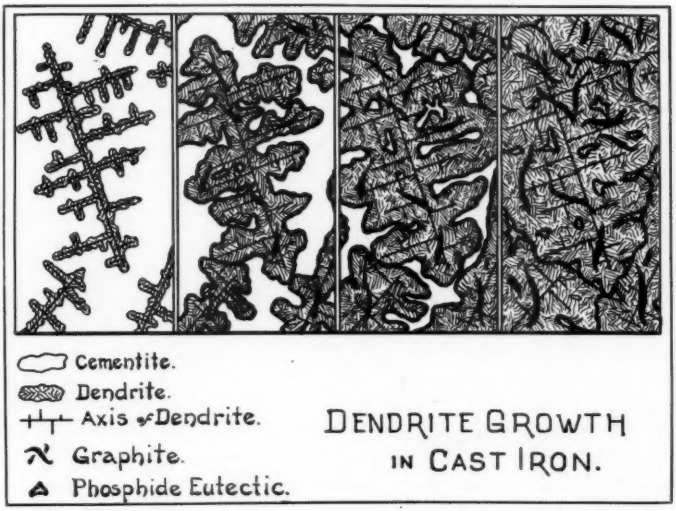

FIG. 22—DIAGRAM SHOWING FOUR STAGES IN DEVELOPMENT OF DENDRITES IN PRESENCE OF SILICON.

long as the temperature is sufficiently high; when it drops to a certain value, growth stops regardless of whether they have only reached the size shown in the first stage of Fig. 22 or any of the later stages. All of the surrounding material will then be cementite.[7]

93. Here is where another characteristic of silicon enters the picture: *The rate of growth of the dendrites at any given temperature increases as the silicon content increases.*

[7] Actually the percentage of carbon present in the matrix is not sufficient in this case to form pure carbide—or cementite—hence it is diluted somewhat with iron, but its microscopical appearance and reaction to most reagents is the same; therefore it is still called cementite.

Silicon in Gray Iron and Chilled Iron.

94. For gray iron the silicon must be sufficient (and, preferably, no more, because of its effect on the pearlite and graphite formation) to allow dendritic growth to become complete before the temperature is reached where growth stops, otherwise there will be free cementite present, as in the third stage of Fig. 22. As the rate of cooling is determined by the mass of metal in the casting and the radiating surface, we can see why the silicon should vary with the weight of casting to produce this result.

95. This is done in chilled irons, so that at the same time, with gray iron in the body of the casting, that in the chilled surface is white, brought about through sudden cooling by means of a metal chiller. The chilled iron corresponds to the first stage of Fig. 22, and under the microscope it appears as shown in Fig. 23.

96. If the silicon be a little higher, not only do some of the dendrites become larger, but graphite is precipitated within them, even in the chill, as may be seen from Fig. 24. This chill will show poor wearing qualities, as compared to that of Fig. 23. Very few chills are ideal insofar as freedom from graphite is concerned, but the less of it present, the better the wearing qualities (other things being equal).

97. If space permitted, we might show a whole series of micrographs with gradually increasing dendrites and corresponding decrease in the amount of cementite. However, it will suffice to show a single example, corresponding to the third stage of Fig. 22. In Fig. 25 the dark areas are, as usual, the dendrites; the white areas in this case are cementite. This is the typical appearance of mottled iron, hard spots, etc.

DISTINGUISHING FERRITE FROM CEMENTITE

98. As cementite has the same superficial appearance as ferrite, from a microscopical point of view, the question arises as to how to tell them apart. How do we know when we have ferrite and pearlite, and when cementite and pearlite?

99. In all the micrographs of etched specimens shown thus far, nitric acid was the etchant. This attacks ferrite but slightly, and cementite not at all (although it does attack the boundary

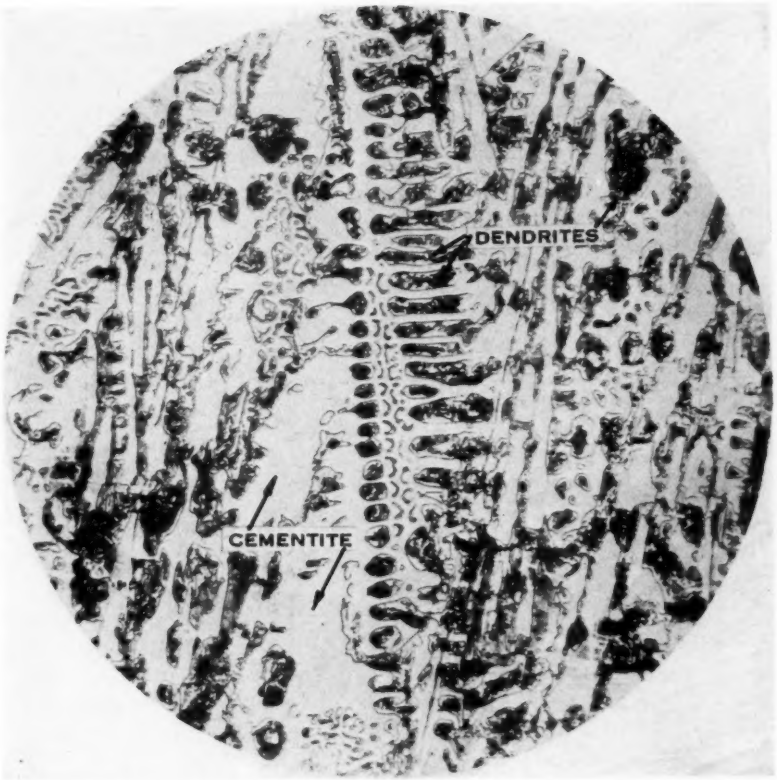

FIG. 23—CHILLED CAST IRON. X 300. HIGH-QUALITY CHILL, PRACTICALLY FREE FROM GRAPHITE.

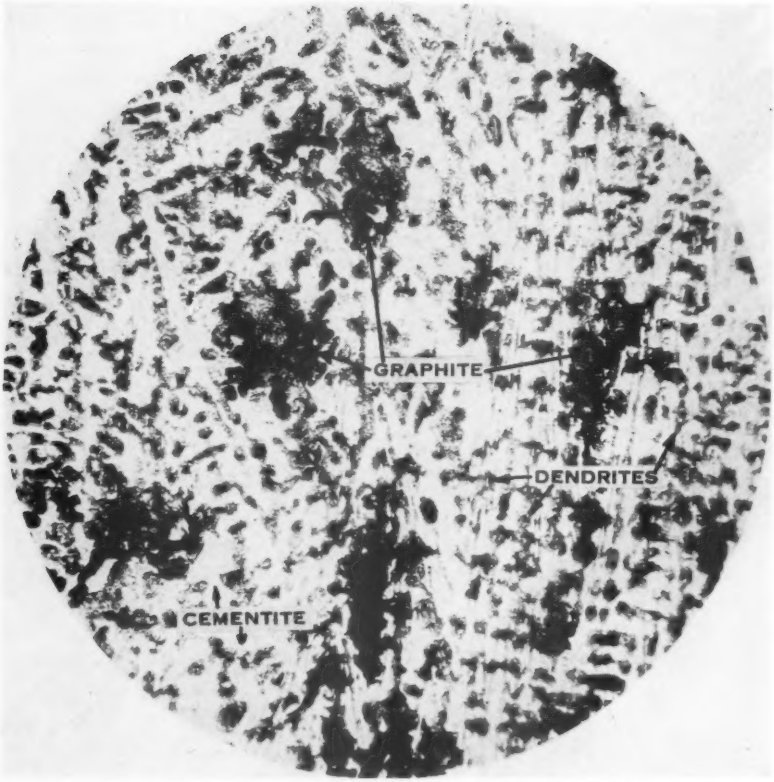

FIG. 24—CHILLED CAST IRON. X 200. POOR-WEARING CHILL WITH CONSIDERABLE FREE GRAPHITE AND SOME LARGE DENDRITES PRESENT.

FIG. 25—FREE CEMENTITE IN GRAY IRON. X 175. TYPICAL HARD SPOT IN CAST IRON, CAUSED BY INSUFFICIENT SILICON TO BALANCE COOLING RATE.

between them); hence the similar white appearance with this etching agent. However, familiarity with the following differences will generally suffice to identify them:

(a) There is a slight difference between them in the shade of white present after a nitric acid etch.

(b) There is a regularity in the positions occupied by the cementite, as it fills the spaces between the dendrites while ferrite always occurs within them.

(c) Cementite never is associated with graphite, while ferrite always is. Graphite never occurs within cementite but does occur within ferrite, just as in pearlite. White areas with abundant graphite always suggest ferrite.

(d) If the etching is sufficient, ferrite appears broken up into grains, while cementite never is broken up. Comparison of Figs. 20 and 25 will make this point clear.

(e) Ferrite never is separated from pearlite by a border line, while cementite always is. Fig. 26 illustrates this point.

(f) Occasional cementite plates, such as occur in pearlite, frequently are visible in ferrite. Ferrite generally is associated with coarse pearlite, very seldom with fine.

(g) In case of doubt, etching by other means, as described in the appendix, will settle the matter.

100. With regard to the presence of ferrite and cementite, cast iron is different from steel in one respect: In the latter, only one can be present at a time; a white area must be one or the other. In cast iron both can be present, side by side, as can be seen in Fig. 26. This condition is more evident, the higher the phosphorus content.

NATURE OF FERRITE, PEARLITE, CEMENTITE AND GRAPHITE

101. It was pointed out early in this paper that only four essential constituents were involved in a simplified microscopical study of cast iron, namely, ferrite, pearlite, cementite and graphite. These constituents are reviewed in following paragraphs.

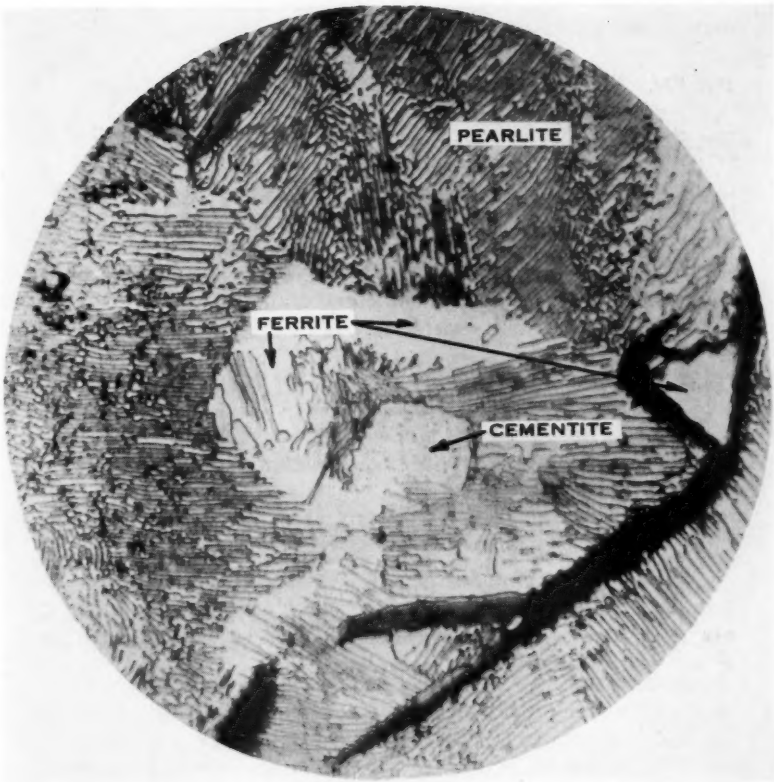

FIG. 26—CEMENTITE AND FERRITE IN CAST IRON. X 1500. CEMENTITE AND FERRITE CAN OCCUR SIDE BY SIDE IN CAST IRON. FORMER ALWAYS IS SEPARATED FROM PEARLITE BY A LINE OF DEMARCATION; LATTER IS A PART OF THE PEARLITE. THIS CEMENTITE IS CAUSED MOSTLY BY PHOSPHORUS (PHOSPHIDE EUTECTIC).

Ferrite.

102. Ferrite is pure iron in the form of crystal grains, generally with other elements dissolved in it but which in no way affect its appearance. Its presence in cast iron results in a very soft but weak product, with abundant graphite; hence, it is undesirable wherever strength is desired.

Pearlite.

103. Pearlite consists of the same ferrite grains having iron carbide dispersed within them, usually as thin plates occupying positions along crystallographic planes, and having an ideal carbon content of about 0.85 per cent. This is the constituent mostly to be desired in cast iron, not only because in itself it is the strongest and toughest that can be present but also because, with maximum pearlite, there is minimum graphitic carbon (assuming freedom from free cementite).

Cementite.

104. Cementite is the name given to a hard, brittle compound of iron and carbon (Fe_3C), which is one of the components of pearlite and which also occurs free in white iron or one in which the silicon is less than required for a certain cooling rate. All of the combined carbon of cast iron is in cementite.

105. As the presence of this constituent in free form results in hard, brittle iron, difficult to machine, it is undesirable in gray iron except in the form of pearlite with a combined carbon of not materially over 0.85 per cent.

Graphite.

106. Graphite is pure carbon which has been forced out of union with the iron by the presence of silicon (or other graphitizing element) and, consequently, occurs scattered throughout the iron as an essential impurity. As it imparts weakness and lack of ductility to iron, the less of it present the better, providing no free cementite is present in its stead. Its objectionable characteristics are minimized by dispersing it throughout the iron in the greatest possible state of subdivision.

107. While knowledge of these four constituents and the means for controlling them would constitute one a fair metallur-

gist for practical purposes in a cast iron foundry, if one were to stop here it would leave the impression that other elements—such as sulphur, manganese and phosphorus—play no part in the nature of cast iron, which is incorrect. Therefore, each of these, as well as other alloying elements, must be discussed.

SULPHUR

108. In the past, sulphur probably has been the cause of more concern than any other element; even now, many specifications limit the sulphur to a very low value. There are reasons for this attitude, but to a large extent they are based upon conditions that can be controlled by other means than by placing unreasonable limits on the sulphur content.

Effects of Sulphur on Iron.

109. Sulphur reacts in two ways, both of which are deleterious to the quality of the iron. In the first place it unites with iron to form iron sulphide, a compound having a very low melting point, hence one that solidifies last, between the grains. As this compound is inherently weak, its presence causes easy fracture and the iron is rendered practically useless.

110. In the second place, sulphur acts to neutralize the effect of silicon in precipitating graphite. As it is possibly from ten to fifteen times more powerful than silicon, it is as though the latter element were reduced an amount equal to ten to fifteen times the sulphur content. This often would result in the presence of free cementite and corresponding hard iron.

111. It can be seen that, on both counts, the elimination of sulphur to the vanishing point is desirable, but fortunately there is a better and easier way out. This is where manganese plays its principal role.

MANGANESE

Manganese and Sulphur.

112. Manganese has such a strong affinity for sulphur that it will take it away from iron and form a new compound, manganese sulphide, having entirely different properties. Moreover, if the quantity of manganese be sufficient, it will search out every particle of sulphur and convert it to the new compound so that

there is practically none left to have any neutralizing effect on silicon.

113. Manganese sulphide, instead of having a low melting point like iron sulphide, freezes at a higher temperature than any other constituent of cast iron. Being lighter than iron, some of it will rise to the top as slag, thus lowering somewhat the sulphur content. However, that which remains is scattered through the iron as minute crystals having no appreciable effect on the strength of the iron.

114. These crystals are referred to as globules in various text books on metalurgy, as they are generally rounded in steel due to the effect of rolling. In cast iron, however, they always appear as dove colored crystals of the cubic system, *i.e.*, square. triangular, symmetrical polyhedrons, etc. (sometimes skeleton forms, in which the crystal development of this constituent still can be traced).

115. They are the only constituent of cast iron besides graphite that can be seen in an unetched specimen, where they appear as shown in Fig. 27. At very high power they appear in an etched specimen as in Figs. 28 and 29. However, they are not as large as they seem here, for at this high magnification (3000x), three inches on the photograph are equal to only 1/1000 of an inch in the metal.

Amount Necessary to Counteract Sulphur.

116. In estimating the amount of manganese necessary to completely scavenge the sulphur, a fairly safe figure is 3½ times the sulphur content. With this ratio, sulphur up to 0.15 or even 0.20 per cent should not be harmful for most purposes. All manganese over the amount necessary to form manganese sulphide goes into solid solution in the iron, so cannot be seen under the microscope.

117. In this condition it probably tends to prevent the full action of silicon on the cementite of the pearlite, thus giving what is often called a more dense iron. It has, however, a rather complex effect on the whole, which has been the cause of much disagreement among metallurgists as to whether it is a softener like silicon or a hardener which tends to hold the carbon in the combined form.

FIG. 27—MANGANESE SULPHIDE IN CAST IRON. X 700. BEING A DIFFERENT COLOR FROM REST OF MATRIX, CRYSTALS OF MANGANESE SULPHIDE ARE VISIBLE WITHOUT ETCHING.

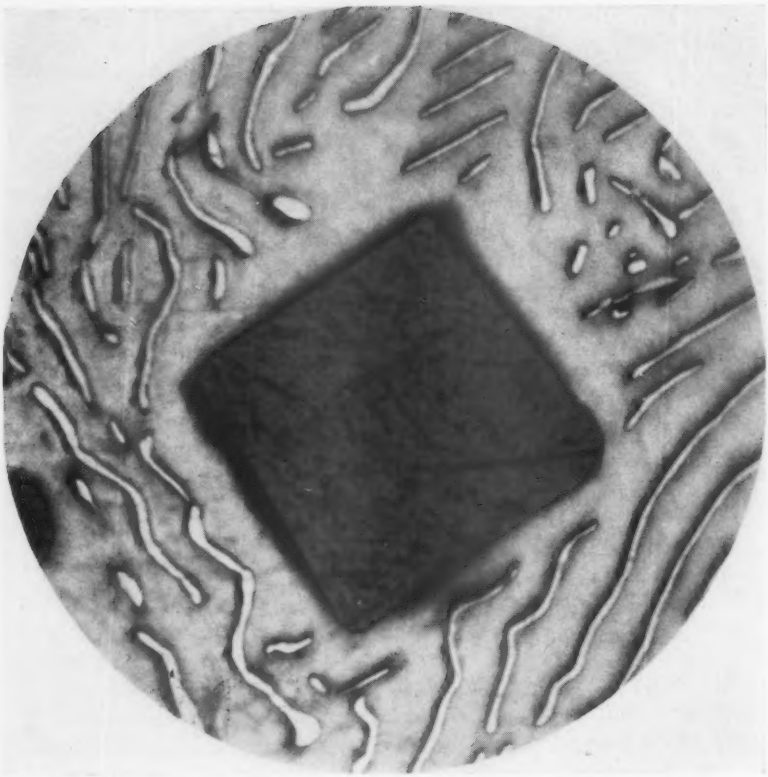

FIG. 28—MANGANESE SULPHIDE CRYSTAL. X 3000. CRYSTAL HABIT OF THIS INCLUSION IS APPARENT. DIMENSION OF THIS CRYSTAL IS 0.0006 INCH SQUARE

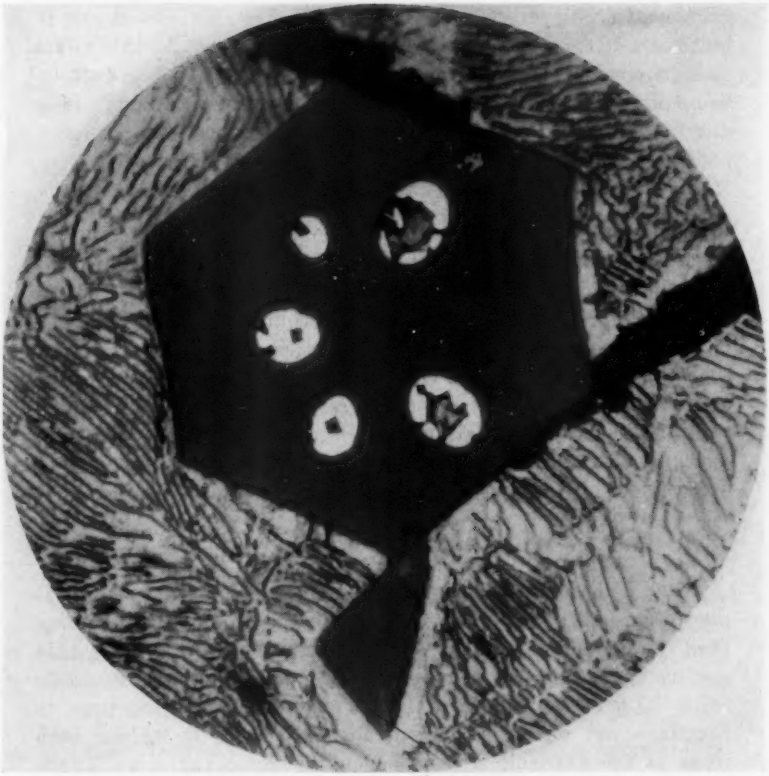

FIG. 29—MANGANESE SULPHIDE CRYSTAL. X 3000. ANOTHER FORM OF CRYSTAL WITH EUTECTIC INCLUSIONS.

Effect in Chill of Chilled Iron.

118. The best place to observe the true effect is in the chill of chilled iron, where it can be demonstrated that it exerts a softening effect on the chill, that is, works *with* silicon, up to the percentage where they are approximately equal, at which place the poorest and softest chill is produced. As soon as the manganese materially exceeds the silicon, the effect is reversed and it becomes a hardener, that is, works *against* silicon. As this seems to hold good at all percentages up to at least 1.25 per cent, it seems logical that it will be true at higher values, although it is difficult to prove in gray iron of ordinary composition.

Modification of Melting and Thermal Critical Points.

119. One other effect can be attributed to manganese (and all other elements entering into solid solution with iron), that is, a modification of the melting and thermal critical points, including the eutectoid point. The belief is quite prevalent that the latter is lowered, but such is not necessarily the case. What actually happens is that the eutectoid percentage is changed from a definite fixed value, as in the case of pure iron, to a fairly wide band, the maximum remaining at 0.85 per cent and the minimum depending on the alloying elements and other factors not as yet determined.

PHOSPHORUS

120. The other element in cast iron deserving attention is phosphorus. This is universally known for its effect in giving fluidity to the iron. It has been thought in the past that thin castings could not be successfully produced without its use in fairly high percentages, but the tendency at the present time, in foundries not scientifically controlled, seems to be to use such irons as are available without much thought being given to the phosphorus content.

Effect on Fluidity.

121. The reason for increased fluidity lies in the formation of an iron phosphide possessing a very low freezing temperature. This is somewhat soluble in the pearlite and ferrite grains, but the bulk of it remains fluid and concentrates between the dendrites

until it finally solidifies with the remaining cementite to form islands of what is known as *phosphide eutectic.*

122. This constituent appears, with a nitric acid etch, like a partially decomposed cementite, as can be seen from Fig. 30. If this were normal cementite it could be destroyed by heat treatment, but phosphide eutectic is quite persistent, apparently because the surrounding pearlite is saturated already with phosphorus, and that of the eutectic has no place to go.

123. The presence of the phosphorus in the surrounding pearlite can be demonstrated by a special etching agent (Stead's) which does not attack iron containing phosphorus as rapidly as that which is free from it. Fig. 31 is taken from a sample etched with a similar etching agent. That the island of cementite is in itself complex can be demonstrated by heat tinting, when the structure is shown to be a true eutectic, as is evident from Fig. 32.

Effect on Strength.

124. While phosphorus does give fluidity, it is at the expense of strength. For this reason it is preferable to obtain fluidity by higher tapping and pouring temperatures when strength is desired. Definite increase in strength can be demonstrated with phosphorus reductions to at least 0.10 to 0.12 per cent, which is contrary to general belief.

Effect on Combined Carbon.

125. The question of the influence of phosphorus on combined carbon in cast iron has been the subject of much discussion among metallurgists. In view of the greater influence of other elements, not much effect can be demonstrated, hence the general opinion is that it is without effect.

126. However, careful deduction from certain microscopical evidence leads to the conclusion that it has a weak influence tending to retain carbon in the combined form, especially when concentrated to the eutectic percentage.

127. Fig. 33, at a magnification of 3000x, shows an island of cementite in gray iron having ample silicon to reduce all free cementite, where the cementite is still in the process of dissolving into pearlite. If the reaction had been completed, the cementite of the phosphide eutectic would have been completely isolated

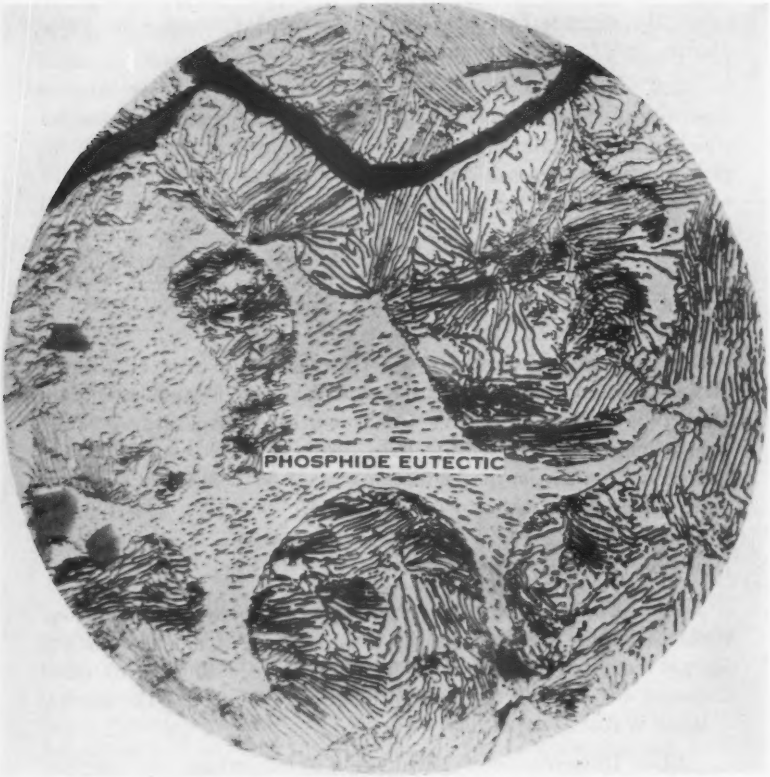

FIG. 30—PHOSPHIDE EUTECTIC. X 1000. TYPICAL APPEARANCE OF THIS CONSTITUENT WHEN ETCHED WITH 3 PER CENT NITAL.

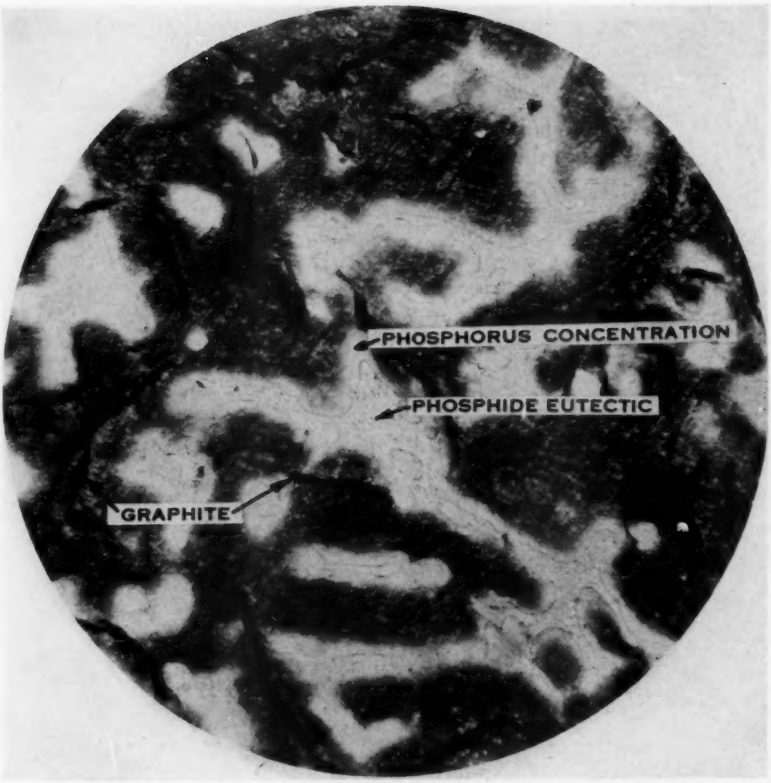

FIG. 31—PHOSPHIDE EUTECTIC. X 200. ETCHED WITH MODIFIED STEAD'S REAGENT TO DEMONSTRATE PHOSPHORUS-RICH AREA (LIGHT BORDER) SURROUNDING PHOSPHIDE EUTECTIC.

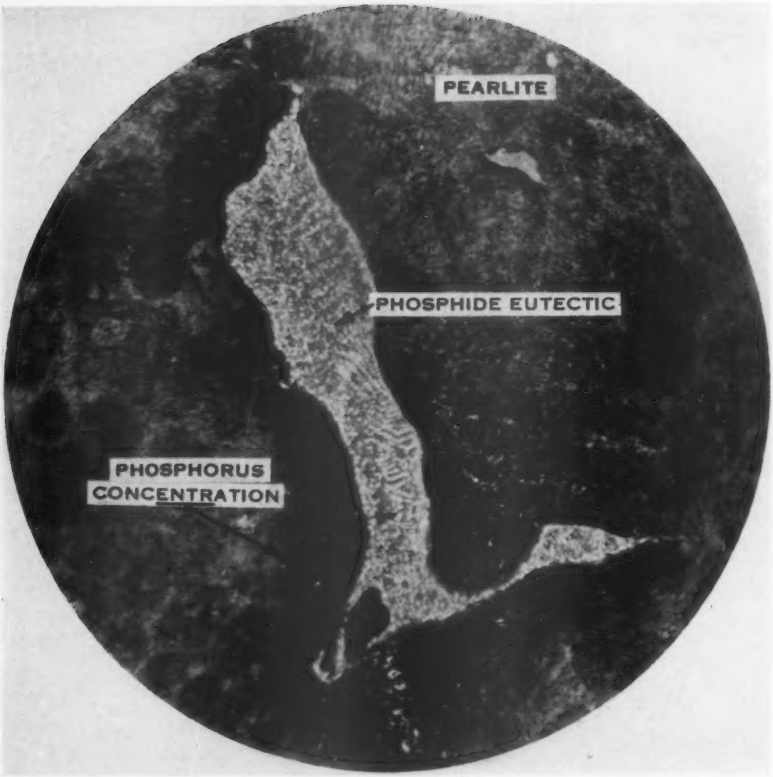

FIG. 32—PHOSPHIDE EUTECTIC. X 1000. TRUE EUTECTIC NATURE OF THE ISLAND OF PHOSPHIDE EUTECTIC IS REVEALED BY HEAT TINTING. CONCENTRATION OF PHOSPHORUS AROUND ISLAND IS SHOWN BY THE DARKER BORDER.

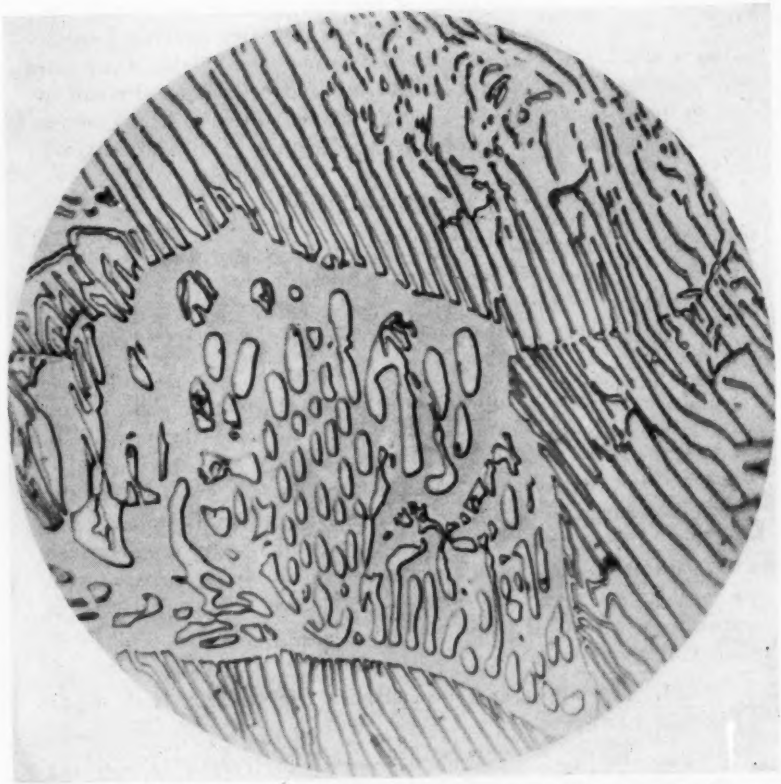

FIG. 33—CEMENTITE DISSOLVING TO FORM PEARLITE. X 3000. SIMILARITY OF MASSIVE CEMENTITE AND CEMENTITE PLATES OF THE PEARLITE IS SHOWN BY CONTINUITY OF THE TWO IN THIS INSTANCE.

from the pearlite, hence it appears as though phosphorus in this case is tending to retard the reaction which silicon is trying to complete.

The Microscope in Studying Working Temperatures

128. Mention was made of the fact that the microscope can be of use in studying the effect of tapping and pouring temperatures and heat treatment. Some demonstration of this was given in showing the effect of superheating and cooling on the nature of graphite and pearlite. Perhaps one or two additional illustrations covering the effect of heat treatment might be of interest.

MALLEABLE IRON

129. The subject of malleable iron is too large to be included in the present paper, but as it represents the most drastic type of heat treatment which is applied to cast iron, it will serve to illustrate what can be done in modifying the structure of the metal.

130. As cast, malleable-iron castings have a chilled iron structure such as shown in Fig. 23, the carbon being practically all in the combined form. The malleablizing process consists of a heat treatment at such temperature as will break down the combined carbon and throw it out as free carbon (graphite), not in the form of coarse scales or plates such as occur in gray iron but rather as small flocculated masses which do not have so great a weakening effect. As practically all the combined carbon is broken down, the matrix is not pearlitic, as in the best gray irons, but entirely ferritic.

131. The appearance of malleable iron at 200x is shown in Fig. 34.

132. In this connection, it may be of interest to note the effect on the chill of a mine-car wheel that was deliberately overheated in annealing, being kept for several hours at a temperature of 1450 degs. Fahr. It was a typical, hard chill but became dead soft, its appearance being as shown in Fig. 35.

133. The similarity to malleable is noticeable, but it still retains evidence of the dendritic structure. Logically, it would seem that if such radical change can be brought about so easily, it should be a simple matter to heat treat castings which are a

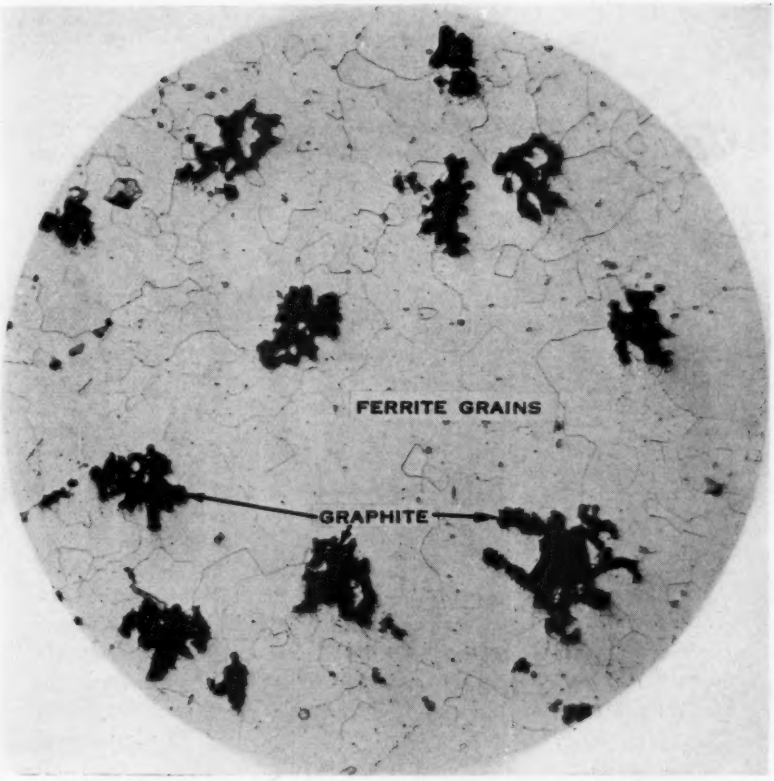

FIG. 34—MALLEABLE IRON. X 200. SHOWING THAT MALLEABLE IRON CONSISTS ENTIRELY OF FERRITE AND FLOCCULATED GRAPHITE. NO PEARLITE IS PRESENT.

FIG. 35—EFFECT OF HEAT TREATING. X 500. SHOWING RESULT OF ANNEALING CHILLED CAST IRON FOR SEVERAL HOURS AT 1450 DEGS. FAHR. CHILL HAS BEEN DESTROYED AND PRODUCT IS ALMOST THE SAME AS MALLEABLE IRON, ONLY A LITTLE PEARLITE BEING PRESENT.

little hard, so as to make them serviceable. There is plenty of opportunity for research along the line of heat treating cast iron, for the subject is still in its infancy.

EFFECTS OF ALLOYS ON IRON STRUCTURE

134. In view of the recent strides which have been made in the production of high-test irons by the use of additional alloying elements such as nickel and chromium, this paper would not be complete without some discussion of their effect on the microstructure of the iron. Although silicon is the universally recognized softener for gray iron, it has been found that other elements operate similarly, notably nickel, copper and aluminum.

Nickel.

135. Nickel especially possesses other properties which make it superior in some ways to silicon, as, for instance, it tends to produce fine grain size, fine pearlite and finely dispersed graphite. Moreover, the iron is not so sensitive to the graphitizing effect of nickel as silicon, requiring about twice the quantity to produce the same results, allowing greater latitude in control. Then nickel in solid solution in iron raises the strength of each individual crystal so that the resultant mass strength is increased.

136. The tendency of nickel to give fine pearlite is well shown in Fig. 10. In this iron about 1.25 per cent of nickel is substituted for half this amount of silicon. As previously mentioned, the fine graphite of this same iron, as shown in Fig. 19, is also the result of the nickel, probably combined with a high melting temperature. The iron shown in Fig. 9 also owes its fine pearlite to nickel, but in the case of this iron some chromium also is present.

Chromium.

137. Chromium acts exactly the opposite of silicon, and its influence is so powerful that an amount equal to the silicon content will entirely neutralize the latter and produce a white iron. This means that it is at least twice as potent as nickel, so that if both are added the silicon can remain constant if the nickel is about two times the chromium content.

Formula to Determine Composition of Castings for Nickel and Chromium Additions

138. Based on these values, a simple formula can be used to determine the approximate composition for castings where it is desirable to try out nickel and chromium additions. First it is necessary to know the silicon percentage that gives the best result. As this varies almost inversely as the carbon content, within the ranges of commercial irons, this latter element can also be varied to suit, and these two together will give us the first part of the formula, which is:

$$TC + Si = X$$

where TC represents total carbon, Si silicon, and X the sum of the two which has proven satisfactory by previous tests. For instance, if the total carbon is 3.5 per cent and the silicon 1.5 per cent for a certain particular casting, then 3.5 plus 1.5 equals 5; that is, X is 5 in this case.

139. If we wish to reduce the total carbon to 3.2, then the silicon must be increased to 1.8 per cent. If nickel is to be included in the formula, as it is only one-half as potent as silicon we get:

$$TC + Si + \frac{Ni}{2} = X$$

For the same casting, X would always be the same, regardless of any change in the first part of the equation.

140. When chromium is added, as it is twice as powerful as nickel and functions in the opposite direction (*i. e.*, must have a negative sign in front) we get the following complete equation:

$$TC + Si + \frac{Ni - 2Cr}{2} = X$$

141. From this it will be seen that if the chromium is over twice the nickel, the silicon must be increased accordingly.

142. This is only intended to apply to those percentages of nickel and chromium ordinarily added to gray iron to improve its physical characteristics without changing its nature. It is possible to completely alter the nature of cast iron by the use of from 4.5 to 6 per cent nickel and 1.5 to 2.5 per cent chromium.

143. Such an iron has been developed for use in chilled rolls, etc. It is no longer pearlitic but has the structure of water-quenched tool steel, *i. e.*, that known as *martensitic*. That the radical difference in appearance from pearlite may be appreciated, Fig. 36 is shown, at a magnification of 4500 diameters. The chilled surface of such an iron may possess a Brinell diamond hardness of over 1000.

144. Still another nickel-chromium alloy cast iron has been introduced for use as a corrosion resistant iron. The alloying percentages in this iron are still higher, with some of the nickel replaced by copper, and the metal is austenitic—that is, it does not transform to pearlite, even down to normal temperatures.

FLAWS AND CASTINGS

145. We have now covered, in a superficial way, the various structures which affect the nature of cast iron, as revealed by the microscope. However, there are other ways in which it can be of service to the foundryman. An example might be cited in the case of flaws or cavities—to determine their nature, cause and means of rectifying them.

146. When actual dirt or foreign matter is to blame for an imperfection, the microscope will show its presence. When a cavity is formed as a result of gas inclusion, the walls are generally smooth, owing to the mutual pressure between the molten metal and the gas. Shrink cavities, on the other hand, always can be identified by the presence of microscopic dendrites growing free, into the cavity, or at least some evidence of crystallographic structure will be present.

147. Fig. 37 shows the appearance of a minute shrink cavity only 1/8 inch long, on the fractured surface of a test bar. Knowing the cause of such flaws, it is possible to take steps to eliminate them.

SUMMARY

148. Summing up, we find that the microscope verifies much that has been learned about cast iron in a purely empirical manner, as well as the results of definite research work. Its value to the foundryman lies in the fact that, knowing what conditions make for high quality and what cause trouble, he can study his

product and determine for himself just how far it falls short of meeting the ideals he has in mind for it, and he can draw conclusions as to the steps to be taken to bring it up to his ideal.

149. In presenting this paper it is realized how extremely superficial it must seem to those who wish it might have been amplified, and how dry and unpractical it will be to those to whom

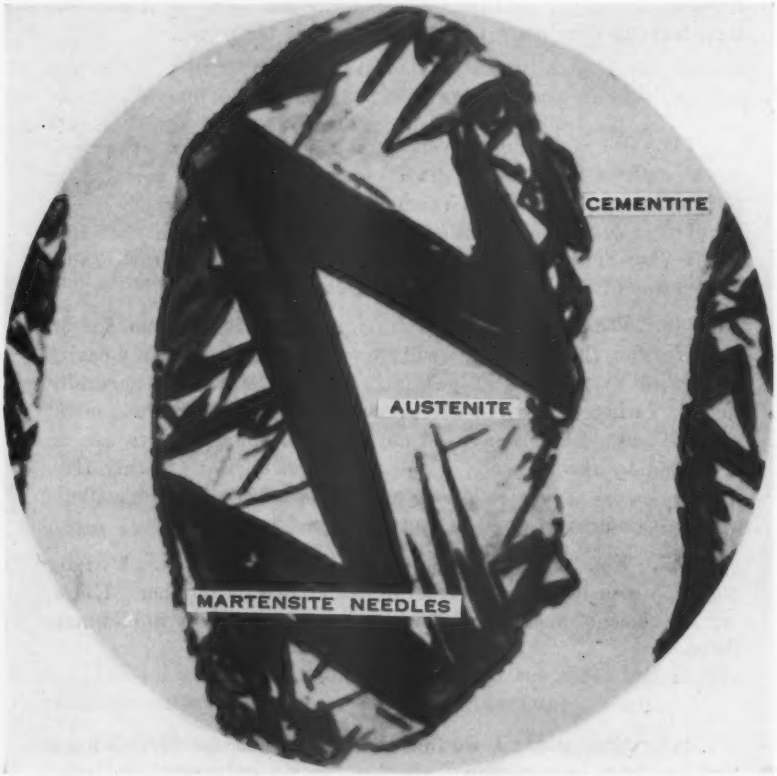

FIG. 36—MARTENSITIC CAST IRON. X 4500. CHILLED CAST IRON CONTAINING ENOUGH NICKEL AND CHROMIUM TO PREVENT TRANSFORMATION OF AUSTENITE TO PEARLITE. INSTEAD, IT TRANSFORMS TO MARTENSITE, NEEDLES OF THE LATTER BEING PRESENT IN A MATRIX OF AUSTENITE.

the technical or scientific method of approach to a problem means nothing. It is hoped, however, that some sort of a happy medium has been attained in the presentation of the subject so as to reach a certain few, and that they, becoming enthused, will aspire to a mastery of the subject far beyond anything that has yet been accomplished.

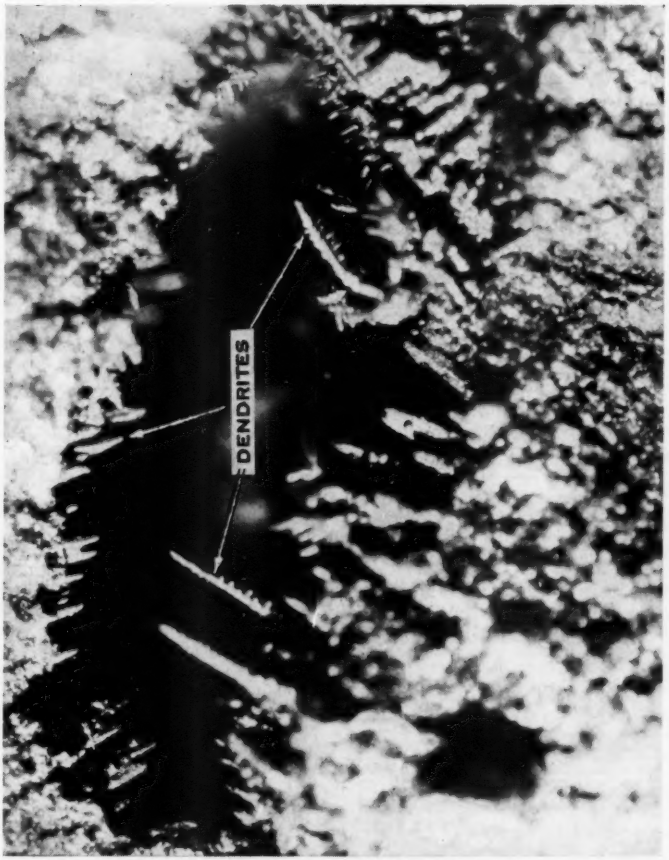

FIG. 37—SHRINK CAVITY. X 45. SHRINK CAVITIES GENERALLY CAN BE RECOGNIZED BY PRESENCE OF MICROSCOPIC DENDRITES PROJECTING INTO THEM. THIS ENTIRE CAVITY IS LESS THAN ⅛ INCH LONG.

APPENDIX

The Microscope

150. As this paper may be of interest to some who are unfamiliar with the microscope itself or the methods employed in its use, its value may be enhanced by a brief discussion of the principles involved in its construction and a few suggestions for getting the most out of it.

151. First of all, let it be understood that there is nothing mysterious about a microscope. It is but a scientific improvement on a pair of spectacles which enable us to see more than we could without them. It is a safe guess that if some enterprising concern were to advertise a pair of magic spectacles for foundry use which would enable one to look at cast iron and determine all the details of its structure, its defects and good qualities, and show how to make it better than his competitor's, every foundryman in the country, after being convinced of the truth of the claims, would begin to save up his pennies toward the acquisition of a pair.

152. Yet just such is the metallurgical microscope. To be sure, it is somewhat too cumbersome to attach over the ears with a pair of wires in the conventional manner, but we do the next best thing, provide it with a base or suitable stand to hold it and, Mahomet like, go to it instead of having it come to us.

Magnifying Parts

153. The magnifying part of the instrument actually consists of two parts: The objective (which is the lens system near the object under examination), and the ocular, or eye-piece (that next to the eye). Each of these serves to give a magnified image of the object on which it is focused.

154. Before discussing the manner in which this is accomplished, it is desirable to understand what is meant by magnification, which after all is only a relative term, as the apparent size of anything we see is determined by the angle of the two lines drawn from the extremities of the object to the eye.

155. Suppose a dime is held ten inches from the eye. The coin will appear to be a certain size, while a silver dollar alongside it will be much larger because the angle which its diameter subtends will be correspondingly greater. If we move the dollar farther away, it reaches a position where its angle will just equal that of the dime at ten inches, and both then will appear of the same size. If there were no way of determining the relative distance of the two from the eye, there would be no way of proving them not identical in size.

Basis of Magnification

156. It has been found that the distance at which the average nor-

mal human eye can see most distinctly is ten inches; consequently, this dimension is used as the basis of magnification. If a nearsighted man can see perfectly when an object is only five inches from his eye, then he sees it enlarged two times over what a normal eye would see, as the angle at five inches is twice what it would be at ten inches.

157. With a normal eye the object at five inches would appear blurred and indistinct, but it is possible to interpose a lens—*e. g.*, a reading glass—between the eye and object which will make it appear sharp. Such a lens would be said to possess a magnifying power of two times.

158. Similarly, if an object were one inch from the eye, it would appear magnified ten times. A lens which would make it sharp at that distance would have a magnifying power of ten times, or to be more accurate, ten diameters (written 10x).

159. The same lenses which we interpose between the eye and object to magnify the latter also can be used to project an image of the object on a screen, just as with a stereopticon or motion-picture machine lens. If we project the image of an object 1/8 inch (0.125 in.) in diameter on a screen 10 inches distant from the lens, and the latter possesses magnifying power of 10x, the image would measure 1.25 inches in diameter.

Objective and Eye-Piece

160. It is this principle which is utilized in the microscope. The objective is the lens which magnifies the object and projects the image onto a hypothetical screen. The eye-piece is a second lens which has for its object the image formed by the objective on the hypothetical screen.

161. It should be understood that there is no actual screen between the objective and eye-piece, as the latter is capable of picking up the image without one and an actual screen would only detract from the sharpness of the final image. This final image is projected into space so that it can be picked up on a screen such as a photographic plate by having all the rays cross outside the eye-piece first, at a point called the eye-point or ramsden circle. It can also be seen by the eye if placed at the eye-point.

162. As the objective and eye-piece must be separated from each other by a definite distance in order to allow the former to project its image to the proper distance, they are mounted on the opposite ends of a tube which also serves to provide supporting and focusing means. All objectives are provided with standard screw threads and thus are interchangeable, and all modern eye-pieces are of a proper diameter to slide easily into the top of the tube.

Magnifying Combinations

163. Both objectives and eye-pieces are obtainable in different degrees of magnifying power so that the ultimate magnification can be

varied at will by having several of each. Suppose we have three objectives with powers of 10x, 20x and 40x, and eye-pieces of 7.5x, 10x and 12.5x. A total of nine combinations is possible here, the product of the two used being the actual magnification of the system. That is, if a magnification of 100x is desired, it is obtained with the 10x objective and 10x eye-piece (10x $\times$ 10x = 100x). The lowest possible magnification with this outfit would be 75x (10x $\times$ 7.5x), and the highest 500x (40x $\times$ 12.5x).

164. With each system employed there is only one position where the object will be in focus, that is, appear sharp and clear to the eye, this depending principally on the objective and being affected but little by the eye-piece. For the 10x objective the distance of its front lens from the object may be about 1/4 inch, whereas the 40x comes within about 1/32 inch of touching the object.

165. The necessity for sharp focusing demands considerable rigidity in the mechanical design of the instrument, also some means for changing the focus at will. This latter is accomplished with two separate adjustments, a rack and pinion (or, in cheap models, a sliding tube) for coarse movement and a fine-motion screw for delicate adjustment.

166. Modern instruments generally are arranged so that both focusing screws turn in the same direction to give the same motion, up or down. Hence, it is possible to know which way the lens is moving when using the fine adjustment. Fig. 38 shows a typical medium-priced metallurgical microscope with the various parts designated.

Illumination

167. It will be obvious that anything to be viewed under a microscope must be properly illuminated, and the intensity of the light concentrated on the spot under examination must equal the square of the magnification in order to appear as bright as when viewed natural size. This is because a magnification of 100x increases the superficial area 100 $\times$ 100 or 10,000 times, and the intensity of the light is the reciprocal of this figure, *i. e.*, 1/10,000.

168. When dealing with opaque specimens like metals, the proximity of the objective introduces a complication in getting the necessary amount of light on the object. Fortunately, however, the intervention of another law of optics renders this problem easy of solution.

169. If an objective disperses light over an area equal to the square of its magnifying power, then if light be sent through it in the opposite direction, it concentrates (or condenses) it in exactly the same ratio. Hence, by the use of a reflecting prism or mirror located above the objective, light can be reflected into it at right angles to the tube and the objective made to do double duty, first as a condenser to illuminate the specimen and then as an objective to magnify it.

170. The prism or plain mirror is known as a vertical illuminator.

In the case of the plain mirror, it is not silvered but is a thin piece of clear glass which only reflects a part of the light and does not prevent the light from passing from the objective to the eye-piece.

171. Either type is available to suit individual requirements. The prism gives a greater concentration of light but is not centrally located with respect to the optical axis; hence, the lighting is somewhat oblique. It also stops off the rays from one-half of the objective, so that its working aperture is reduced. On the other hand, the plain mirror involves considerable loss of light and a stronger light source is required. It is preferable, however, for most purposes.

172. When very low power objectives are employed, the distance between the lens and object is sufficient to allow light to be concentrated on the latter from the side. Such method of lighting is known as oblique illumination and is sometimes desirable for examination of flaws, cavities, broken surfaces and similar conditions where shadow effects help to interpret what is seen.

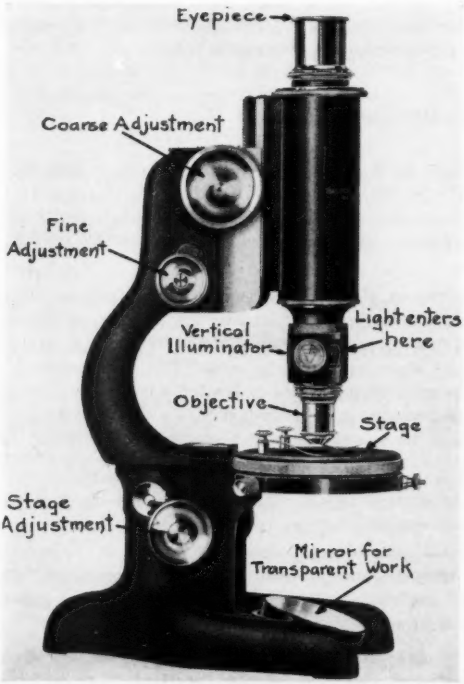

FIG. 38—A SIMPLE FORM OF METALLURGICAL MICROSCOPE.

173. It should be pointed out in this connection that the ordinary microscope gives an inverted image, the object appearing upside down and the light coming from the side opposite the source of illumination.

174. When viewing rough objects such as a fractured surface, only those portions lying in the actual plane of focus will appear sharply defined. All others will be more or less hazy, depending on their distance from the focal plane. By varying the focus with one or the other focusing screw, all parts can be studied in sequence and their vertical relation ascertained.

175. In viewing a polished surface lying at right angles to the optical axis of the microscope, by means of oblique illumination, it appears dark as the light is reflected to one side and does not enter the objective; a roughened surface appears lighter, as it breaks up the light and some of the rays are picked up. This is exactly the opposite of the effect obtained when the vertical illuminator is employed.

176. In the latter case a polished surface is intensely bright, as it functions like a mirror and returns the light along the axis of the microscope from whence it came. A rough surface such as is the result of etching appears darker, as so much light is dispersed in other directions and less enters the objective. It is important to understand this condition so as to interpret properly what is seen.

Importance of Illuminating System

177. Almost as important as the microscope is the illuminating system employed, as without proper lighting the former is of little use. Manufacturers of metallurgical equipments supply suitable illuminators for visual purposes, either attached directly to the microscope or on a separate base.

178. Preference should be given to the particular illuminating apparatus provided by the manufacturer for his own make of microscope, as it is important that the cone of light impinging on the illuminator be of a definite angle in order to secure the best results. Some illuminators have a condensing system mounted directly on them, others have the entire condensing system embodied in the illuminating apparatus, and still others have one condenser on the illuminating apparatus and another on the vertical illuminator.

Principles of Illumination

179. In case anyone possessing a microscope should desire to work out his own method of illumination, the following general principles should be understood:

(a) Neither diverging nor parallel rays should strike the reflecting surface of the vertical illuminator—they should be slightly converging.

(b) The angle of the illuminating cone which strikes the back lens of the objective should equal that of the emerging cone which is projected into the eye-piece by the objective.

(c) The diameter of the cone of light should be just sufficient to cover the back lens of the objective. Generally this is accomplished by means of an iris diaphragm associated with the illuminator.

(d) The diameter of the light source projected on the object should be just sufficient to cover the area included in the eye-piece circle. This is accomplished with a diaphragm associated with the light source.

(e) If the above conditions are met, a relatively small light source, such as an automobile or miniature lamp having a concentrated filament, is ample for visual purposes.

Biological Microscopes for Metal Examination

180. The question frequently is asked as to whether microscopes intended for biological purposes can be used for the study of metals. In general the answer is "No," but if an instrument of this type be available and a metallurgical microscope is not, knowledge of the reasons why the former type instruments are unsatisfactory will show how their objectionable features can be overcome and considerable work accomplished with one of them.

181. In the first place, all biological microscopical investigations are carried out on glass slides, the object being covered with a thin cover-glass and viewed with transmitted light. This necessitates the objectives being corrected to work through the cover-glass, while metals are studied without a cover.

182. With very low powers this is not a serious matter, but when higher power objectives are used, it ruins definition. The whole optical system of the microscope is so sensitive to this condition that, even in biological work, if an objective be corrected to work through a cover 0.18 mm. thick, a difference of 0.03 mm. (about 0.001 inch) in the thickness of the glass materially affects the definition.

183. Then again, the objectives are corrected for a definite tube length, that is, the distance between the objective and eye-piece. The use of a vertical illuminator adds considerable to the length of the tube, necessitating objectives for metallurgical purposes being corrected for a greater tube length. It also is necessary to have the back lens of the objective quite near the vertical illuminator so as to eliminate internal reflections; hence, special short-mount lenses are designed for metallurgical purposes.

184. All of this means that a biological microscope would have to be equipped with metallurgical objectives and a vertical illuminator provided if it is to be employed for metallurgical use.

185. Another serious defect of the biological instrument in metallurgical work lies in the fact that the illuminator, being mounted on the microscope tube, moves up and down with the latter when being focused. This results in throwing out of alignment the beam of light projected into the illuminator. This condition can be overcome by the use of a lamp also mounted on the tube so that everything moves as a unit.

186. In metallurgical miscroscopes this is provided for by an additional focusing arrangement which moves the stage instead of the tube.

Lenses for Higher Magnifications

187. For ordinary work with cast iron it is not necessary to employ objectives with an initial magnifying power of more than about 40x. A 20x eye-piece with this objective would give a magnification of 800x. Lenses up to this power are known as dry lenses, that is, they work with air between them and the object.

188. Higher magnifications necessitate the use of oil-immersion objectives, which are quite delicate and expensive. They are called oil-immersion lenses because a drop of thickened cedar oil is placed between their front lens and the specimen, which provides for a larger cone of light entering the objective and gives greater resolution. They almost touch the specimen when in focus, thus introducing the possibility of accidental damage to the front lens unless great care is taken when working with them.

Fractured Surfaces, Etc.

189. While it is possible to do considerable work with a low-power objective (about 3x) and oblique illumination on gross objects such as fractured surfaces, cavities, flaws, surface finish, etc., the low-power binocular microscope will be found to be far superior for this class of work. Every foundry that can possibly afford it should not be without one.

190. A simple form of this instrument is shown in Fig. 39. Its advantages lie in the stereoscopic image which it gives, making everything stand out just as in ordinary vision; in the fact that the image is erect instead of inverted as in the regular type; in the large working distance between the specimen and lens so that objects can be held in the fingers and moved about for examination, and in the ease with which relatively large objects can be examined.

Large Objects

191. With regard to the examination of large objects, there is considerable difference between various models of the regular type in their adaptability for this purpose. Some can be used only for such objects as can be placed on the microscope stage (that shown in Fig. 38 is of this type); others have a removable stage and sufficient adjustment to allow focusing on the surface on which the instrument rests. In some, provision is made for removing the entire base and substituting a low form such as shown in Fig. 39.

Photomicrography in General

192. The subject of photomicrography is entirely too large for proper presentation in this paper. Its value to metallurgists is rapidly becoming more and more apparent, and without doubt most foundries that go into microscopical work on their problems sooner or later will find it desirable to take up photography in connection with it.

193. While micrographic equipment is somewhat expensive, this is partly compensated for by the fact that it is now designed so that theoretical knowledge of the apparatus is hardly necessary. It has almost reached the stage of the old-time camera slogan, "You press the button, we do the rest."

194. Undoubtedly there will always be some who like to take up new lines and experiment for themselves. If these possess a knowledge of the fundamentals of photography and have metallurgical equipment available, it is possible to accomplish much in the way of taking photomicrographs with home-made equipment.

195. As pointed out, the rays of light which emerge from the eyepiece, if projected to a distance, form an image on a screen. Consequently

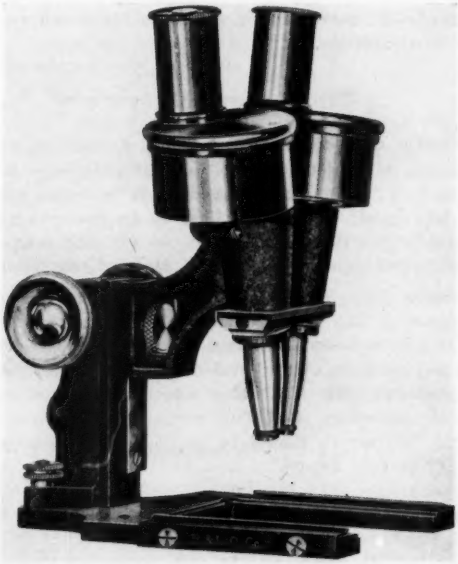

FIG. 39—A SIMPLE FORM OF BINOCULAR MICROSCOPE FOR USE WITH ROUGH SURFACES WHERE LOW-POWER, THREE-DIMENSIONAL MAGNIFICATION IS DESIRABLE.

a camera without lens but equipped with a ground glass for focusing, placed so that the image from the eye-piece is projected on the ground glass, will make a picture.

196. A few conditions must be adhered to, however, in order to obtain results. These conditions are as follows:

(a) Careful alignment of the microscope and camera, and rigid mounting for both. Either vertical or horizontal position can be used, as convenient.

(b) Light-tight connection between them, without mechanical connection, as such would result in disturbing the focus when operating the camera to expose the plate.

(c) A powerful light source such as an arc lamp is desirable, and attention must be paid to the rules for illumination previously outlined.

(d) With ordinary objectives, a green screen interposed in the light path is desirable, as the correction of the objectives for photographic purposes is not ideal.

(e) The magnification of the visual system is obtained when the ground glass of the camera is ten inches distant from the eye-piece, but any distance can be used as desired. At five inches the magnification is one-half that at ten inches, while at twenty inches it is twice that at ten inches. In other words, magnification increases as the bellows length increases, but resolution will suffer after the maximum resolution point of the objective is exceeded.

Care of Microscopic Equipment

197. Whatever microscopical equipment a foundry possesses, whether monocular visual, binocular, or photomicrographic, one point must be constantly borne in mind if the equipment is to retain its high-quality performance indefinitely. Ordinary dust is an enemy of both the mechanical and optical parts of an instrument, but the sand-laden dust of a foundry will work havoc with the soft glass of the lenses.

198. Freedom from dust and continual care that no sand scratches the optical parts of the outfit will pay dividends, insofar as the cost of the apparatus is concerned. Lenses should never be touched with the fingers or wiped with anything but lens paper or soft well-washed cotten or linen handkerchiefs. Cleaning lenses should not be done except when absolutely necessary, and then very light pressure used. When not in use, the instrument should be in its case or covered with a bell jar or other protecting means.

PREPARATION OF THE SAMPLE

199. In most cases it is necessary that the sample of metal to be examined be properly prepared by grinding and polishing a flat surface, generally followed by a suitable etch in an acid or other reagent

which will develop the structure by differentiating between the various constituents.

200. As much of the success of a microscopical study of a metal depends on the perfection attained in the preparation of the sample, a rather detailed outline of the methods employed is warranted. The work, while not hard, may seem tedious until after it is mastered. Therefore, good advice for starting out will be: "Don't try to rush the various operations; realize that a little patience is necessary."

Size of Specimen

201. The size of the specimen is the first consideration. Because of the advisability of examining a given section in order that differences within it can be determined, it is not always possible to confine the size to an ideal dimension. After working for some time with samples of various size, it will be found that there is a preferred size—if the surface is too small, there is a tendency to round it in the polishing operations, thus making examination difficult; if it is unduly large, the time required for grinding and polishing becomes relatively much longer.

202. Where it can be cut to any convenient size, a dimension of from 5/8 to 3/4 inch square and about one-half as thick will be found most suitable. If the thickness is too great in comparison with the surface dimensions, there is a tendency for the polishing wheel to catch on a corner, due to tipping it, and it may be jerked out of the hand. Also rounding of the edges is apt to occur.

Securing a Polished Flat Surface

203. After cutting to size and determining which side is preferable for examination, the next step is that of securing a flat surface. This, of course, may be prepared in any suitable way, as by machining, filing or grinding. The latter is the common method but, in any event, the steps immediately following are classed as grinding operations.

204. The result of the first grinding is a course, rough surface, entirely unsuited for microscopical examination not only because of the lack of smoothness but also on account of the effect of the grinding on the underlying metal. It is important that this fact be thoroughly grasped if proper preparation of a metal surface is to be achieved.

Vital Importance of Eliminating Scratches

205. When a metal surface is scratched with a material harder than itself, the effect extends deeper into the metal than the actual depth of the scratch. The metal surrounding the scratch is no longer in its normal state, because there has been a flow or disturbance in it.

206. This means that even if the scratch is polished out so that it is no longer visible, the metal underneath the scratch is easily attacked

by the etching agent and the scratch reappears. Even when it does not look like a scratch, the abnormal condition of the metal is apparent.

207. If, instead of a single scratch, the entire surface of the specimen be the combined result of thousands of scratches, it is obvious that the exact nature of the metal cannot be determined, regardless of how fine a surface polish may be given it.

208. Therefore, the entire process of grinding and polishing a metallurgical sample for microscopical examination should be conceived of as a series of operations designed to remove all metal which has been distorted, in such a way that additional distortion does not occur. This naturally involves the removal of a considerable amount of metal, which is accomplished in several steps by the use of grinding material of increasing fineness.

Methods of Grinding

209. Three different methods of grinding are commonly employed, first, by the use of solid grinding wheels of several degrees of fineness. If only one spindle is available, this method involves continual change of wheels.

210. Some metallographic polishing outfits on the market have provision for several wheels, permanently mounted, or use horizontally running disks which are easily lifted off for changing. Sets of three wheels —coarse, medium and fine—are placed on the market by several manufacturers of wheels or polishing machines.

211. The second method employs emery or carborundum paper of various grades mounted on brass disks by means of a ring pressed over the edge. Such disks generally are run horizontally on a vertical spindle, which provides for easy change from one grade to another but, of course, can be fitted to run vertically in a small lathe, if desired.

212. If several such disks are available, they can be set up with an entire range of papers so as always to be ready. New paper can be easily applied when the old becomes so worn that it will not cut. When using papers in this manner, it is advisable to do the first grinding on a medium-grade carborundum wheel; then paper grades Nos. 1, 0, 00 and 000 will suffice.

213. The third method involves grinding by hand on papers of the grades mentioned for machine grinding. Special holders are on the market for holding the paper stretched over a flat surface, but, although helpful, are not actually required. However, a true flat surface to back up the papers is necessary.

Procedure of Grinding

214. Whichever method is employed, the procedure is the same. The sample is kept in contact with the abrasive without allowing it to rotate until a series of parallel grinding marks are present and the effect of the previous grinding operation obliterated. Each time a change in the

abrasive is made, the specimen is rotated approximately 90 degrees so that the new scratches will be at right angles to the old. In this way it is easy to note when all the previous marks have been removed.

215. As pointed out, this does not necessarily mean that we have gotten below the *effect* of the previous grinding. It is a fairly safe rule that the metal below the scratch is not disturbed for a distance greater than the depth of the scratch. Therefore, if the time it takes to completely obliterate the marks of the previous grinding be noted, then grinding continued for an additional time equal to that required to remove the scratches, we are pretty sure to be safe. The new abrasive, of course, in addition to making a new set of marks, also disturbs the metal beneath, but, being finer, the depth affected is correspondingly less.

216. In each case, when using grinding papers, it is necessary to be sure that they are cutting and not merely polishing. It is possible for even a No. 1 or No. 0 paper to become so worn that it no longer cuts but will still put on a gradual polish equal to that of the finest paper. Yet in such case the disturbed metal below is not removed and the appearance after etching is false.

217. While grades of paper up to No. 00000 are made, cast iron and steel do not require finer than No. 000. This grade can be used in its sharp cutting condition to run a specimen after No. 00; then, after becoming well worn, it can be used again on the specimen at right angles to the former grinding direction. This will result in a semi-polish and will give a good surface for the final polishing operation.

218. A trick which is especially advantageous at this stage of the work is to wash off the worn No. 000 paper with denatured alcohol, rubbing well with the hand and finally flooding with fresh alcohol to remove all loose grit. This results in a wonderfully smooth surface for the last operation before going to the polishing wheel.

Polishing

219. Having brought the specimen thus far, we now are ready to polish it. It is almost essential that the polishing operation be performed on a revolving wheel, as hand polishing would be entirely too laborious and time-consuming to justify its use.

220. A flat, nonferrous disk, such as described for use with mechanical grinding, is provided with a heavy grade of canton flannel, soft side up. Care must be taken to keep this wheel free of loose emery from the grinding operations, because a single grain will work havoc with the finish.

221. For ordinary polishing purposes, levigated alumina is preferable, although other material—such as powdered rouge, gray tin oxide (putty powder), etc.—can be used. The procedure is the same for all.

222. About an ounce of the powder is shaken up with distilled water in a wide-mouth bottle, the bottle then filled with water to the brim (this to allow coarse particles that might settle on the sides of the bottle

to drop to the bottom) and allowed to settle for a few minutes. Only the material remaining in suspension is to be used, the upper portion of it being decanted into a wash bottle or one provided with a glass tube through which it can be applied to the wheel as necessary.

223. The polishing wheel should revolve at about 300 r.p.m. and should be kept wet with the solution. Excessive pressure of the specimen on the wheel should be avoided, and it must be continually revolved so that the polishing is not done in any one direction, otherwise pitting is apt to occur. As a rule, only about five minutes polishing is required for cast iron, but the specimen should be examined before etching so as to make sure that scratches are all removed.

224. While high-power photomicrography requires a more critical polishing with a still finer material—magnesium oxide—for ordinary work the extra operation is not necessary, and after it leaves the alumina wheel it is ready for etching.

Etching

225. For study of the nature and distribution of graphite, etching is not required, but must be resorted to for other purposes. Etching is a process of slightly attacking the surface of the metal with some reagent which acts differently on the various constituents present so that they may be made evident.

226. When unetched, the entire surface (graphite excepted), having a high polish, acts like a mirror and under the microscope therefore appears brilliantly white (manganese sulphide crystals are dove gray in color). Whatever constituents are attacked by the etching agent have the luster removed and their appearance altered, hence are made evident.

Etching Reagents

227. Many different reagents have been proposed for etching purposes, but it is not necessary to consider more than one for regular use with cast iron, with a few more for special conditions. A 3 per cent solution (*i. e.*, 3 parts and 97 parts) of nitric acid in methyl alcohol is very satisfactory. In cases where it acts too quickly, it can be further diluted to 2 or 1 per cent.

228. Ethyl alcohol is, of course, equally satisfactory as the diluent but more expensive and sometimes hard to obtain. Denatured alcohol is not so good as it contains adulterants which leave a greasy or oily surface. It is important that the surface to be etched be free of grease or oil, hence should not be touched with greasy fingers after polishing.

229. Before placing in the etchant (often called "nital," a contraction of nitric and alcohol) it should be well washed in methyl alcohol. From 5 to 30 seconds is generally sufficient in the etchant, after which it should be well washed in running water and methyl alcohol, then quickly dried with a soft cotton cloth. The surface should not be rubbed hard or it may be scratched.

Mounting

230. It is now ready for examination under the microscope, but to do this it must be mounted on a glass slip (standard 3 x 1 microscopical slide, thick) in such a way that its surface is exactly parallel to the microscope stage. Various leveling devices are on the market to do this, but they are not actually necessary. The medium used for attaching the specimen to the slip is ordinary modeling wax (plasticene), a piece as big as a small marble being rolled up between the fingers, placed on the slip and the specimen placed over it.

231. To accomplish the leveling, a set of rings should be provided of various depths (3/8 to 3/4 in.) and about 2 in. inside diameter, cut off in a lathe so the sides will be parallel. A ring is chosen which is just a little deeper than the height of the specimen, placed over the specimen and plasticene on the glass, and the specimen pressed down by means of another flat plate until the latter rests firmly on the ring. The specimen will now be embedded in the wax and the top surface will be parallel to the glass, which now can be placed on the stage of the microscope, completing the preparations for examination of the metal.

Examination of Metal Specimen

232. Sometimes it is necessary to distinguish between ferrite and cementite, which appear somewhat alike when nital is used for etching. In such cases there are two other etching agents which give positive determination. These are boiling sodium picrate and a 10 per cent solution of ammonium persulphate in water.

233. The former turns cementite black (or a dark brown) but leaves ferrite perfectly white. The latter attacks ferrite very rapidly (5 to 30 seconds), making it appear very dark; but it has no effect whatever on cementite, which thus stands out beautifully white in bold relief.

234. For cheapness and convenience the ammonium persulphate is to be preferred, as sodium picrate does not keep and has to be made up specially each time it is used. However, for the benefit of any who might require the latter for a special purpose, the method of making and using it is given below.

235. Dissolve 25 grams of sodium hydrate (sticks) in 100 cc. distilled water, then add 2 grams of picric acid. Heat to boiling point until the picric acid is all dissolved, when the solution will be a dark brown. Place the specimen, previously cleaned with alcohol, in the solution and boil for 10 to 20 minutes, when the specimen should have a discolored brownish color, depending on the amount of cementite present. If none is present it will remain white, but sometimes a white specimen still will show a little cementite.

236. Thus, a careful examination always should be made, even if the specimen does not appear to have taken on a color. As with all methods of etching, the specimen should be washed well and dried quickly.

237. For the study of phosphorus segregation, a reagent known as Stead's is usually employed. This is an acidified solution of a copper salt which possesses a strong electrolytic reaction with iron, removing some of the latter and depositing copper in its place. The action is reduced when phosphorus is present, and the position the phosphorus occupies in the metal is revealed.

238. A modification of the formula seems to give somewhat superior results on cast iron. This modified formula is as follows:

Copper chloride.....10 grams
Copper ammonium chloride.....40 grams
Hydrochloric acid.....10 cc.

239. Dissolve in a test tube with heat, using the least possible amount of water, then add it to 1000 cc. of methyl alcohol.

240. The etching action of this reagent is quite rapid and a few seconds may suffice. It is better to under-etch and examine with the microscope until the differentiation is satisfactory, for it must not be allowed to etch too deeply. The result should appear as in Fig. 31.

241. The nature of the phosphide eutectic as shown in Fig. 32 is developed by heat tinting. In this case the oxygen of the air is the active agent. Everyone is familiar with the colors taken on by steel when drawing the temper—they pass through a range of colors in succession, finally becoming a dull oxide color. Cast iron will take on the same colors on a polished surface when heated, but when phosphorus is present the color is delayed a little.

242. Hence, at any stage, there is a difference between the phosphorus-bearing and phosphorus-free metal. This is true not only of the pearlite and ferrite but the cementite as well; consequently, phosphorus segregation can be shown in the former and the eutectic nature in the latter.

243. With these few etching methods at his disposal, the average cast iron foundryman should be well equipped to study his product.

DISCUSSION

WRITTEN DISCUSSION

C. L. SHAPIRO:* Mr. Allen is to be congratulated on presenting such a clear, forceful paper, which brings the study of metallography of cast iron within the scope of every foundryman. Much can be said on the metallurgy of cast iron, but as this paper is dealing mainly with the

* Chemical Engineer, Chelsea, Mass.

essentials, I wish to contribute a few additions to this valuable method of analysis.

Silicon in cast iron varies from 0.50 to 3.50 per cent. It combines with iron in the ratio 1:3 to form solid solution of FeSi. Silicide of iron is not readily detected under the microscope, as it forms a solid solution with ferrite which increases the acid resistance, resulting in a longer etching period. The greater the amount of silicon in solution, the longer the etching time.

It is the influence of silicon and not the percentage present that produces its physical properties in cast iron.[8] There is no special effect in iron up to 3 per cent silicon in the absence of carbon.[9] Silicon will increase the specific volume of iron 0.00117 cu.c. on the addition of 1 per cent.[10]

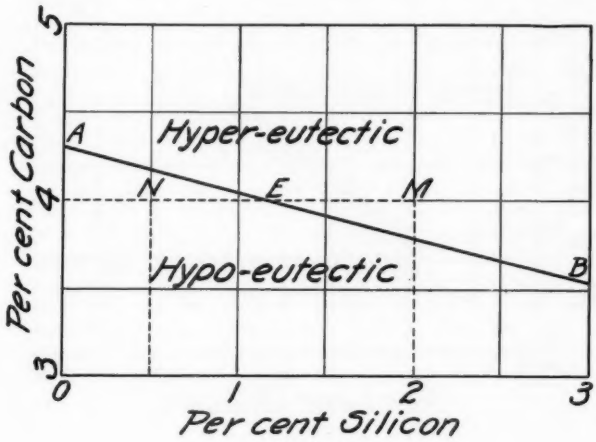

FIG. 40.

Fig. 40 shows the influence of silicon content on the percentage of carbon in the eutectic alloy. Line *A-B* divides cast iron into hyper-eutectic and hypo-eutectic metal, according to its percentage of carbon and silicon.

With 4 per cent carbon and 2 per cent silicon, for instance, the cast iron is hyper-eutectic, since its composition is represented by the point *M* in the hyper-eutectic range; while with the same amount of carbon but in the presence of only 0.5 per cent silicon, the metal is hypo-eutectic, the composition being represented by the point *N* in the hypo-eutectic

[8] Keep, "Cast Iron."
[9] R. Moldenke, "Foundry Practice."
[10] Benedick, Doctorate Thesis, Upsala University.

range. Any point on the line *A-B* will give the eutectic alloy with varying percentages of carbon and silicon.

Fig. 41 shows the influence of silicon content and of rate of cooling in determining the character of the matrix of cast iron. Any point on the line *A-B* corresponds to a set of conditions producing a eutectoid matrix, while any point above *A-B* will produce a hyper-eutectic, below a hypo-eutectic metal. Points *M* and *N* form a eutectoid matrix but not identical properties, because the quicker cooling of *N* will produce smaller and less angular graphite particles, and hence, a stronger metal.[11]

Manganese combines with sulphur, oxygen and carbon. MnS, due to its high melting point—1500 to 1600 degs. Cent.—is practically insoluble in molten iron and always rises to the top of the bath, but sometimes

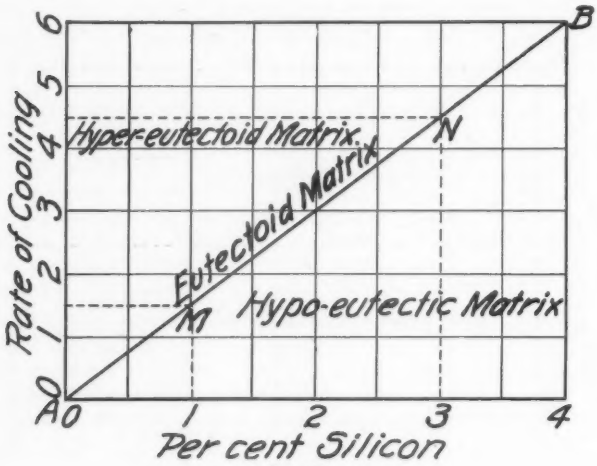

FIG. 41.

it is entrapped in the metal and shows up in the middle of the grain in its characteristic dove-gray color.

MnO is slightly soluble in molten iron and forms a solid solution with FeO. The excess Mn forms Mn_3C, which in turn dissolves in Fe_3C (cementite) and acts as a hardener. In large portions, Mn_3C increases the difficulty of machining castings.

True pearlite is always distinctly lamellar. Sorbite, which often is mistaken for pearlite, is not lamellar but granular.

Spheroidized pearlite has the maximum ductility and softness, minimum hardness and strength of all the constituents of iron and steel. Spheroidized pearlite is made by heating the metal for a long period at a temperature close to its critical range, and cooling slowly.

Sorbite is the first step toward spheroidized pearlite. It increases

[11] Sauveur, "Heat Treatment of Iron and Steel."

the machinability of the casting. After machining it is heat treated in order to increase the strength and hardness. It is very seldom that the casting is left in the spheroidized condition.

It is the common belief that silicon will increase the dendritic growth of cast iron. The mechanism of the theory is that with the greater addition of silicon, the larger and wider will be the graphite flakes, which will act primarily as an axis forming a larger dendrite.

Tests made by the writer on the effects of silicon on the macrostructure of cast iron showed that with the additions of silicon the dendritic structure of the cast iron did not increase, which may be true in pure iron but not in cast iron, since there are other elements which have a tendency to reduce the grain size and counteract the effects of silicon.

The procedure of the above tests were as follows: Ingots were made of a very high grade of gray cast iron which were 3x3x2 inches in size. One ingot was covered with sand, another air cooled, the third water quenched. The ingots were quenched as soon as a skin was formed and while the interior still was molten. Using this high-grade iron as a base, the procedure was repeated three times with the addition of a known amount of silicon, twice this amount and four times this quantity, making a total of 12 ingots.

The ingots were polished and etched with LeChatelier's reagent for macrostructure. The gray iron sand-covered structure showed dendrites at 30 diameters under the microscope. The air-cooled gray iron showed dendrites at 100 diameters; also, the sand-covered ingot with the addition of one amount of silicon, which should have had larger dendrites than the ordinary cast iron, revealed smaller ones as they could only be seen at this magnification. The nine other ingots revealed no dendrites at 250 diameters.

If silicon increased the dendritic growth as believed, the sand-covered samples should have revealed it; but they did not. Therefore, it seems reasonable to assume that silicon does not increase the dendritic growth in cast iron.

A. L. BOEGEHOLD:* The paper by Mr. Allen contains a number of exceedingly fine photomicrographs of the microstructure of cast iron and, with their explanation, should form a valuable supplement to other works on this subject for the man who desires to acquaint himself with all phases of the microstructure of cast iron. The writer, however, is entirely out of sympathy with the purpose stated in paragraph 1, to offer this information as a complete tool to the man who now has no knowledge of this subject.

The writer's experience has convinced him that an attempt to use passing acquaintance with some of the microstructural constituents in metals will result in the drawing of incorrect conclusions approximately ten times out of ten. It may be said that the so-called expert who has

*Metallurgist, General Motors Research Laboratories, Detroit.

a reasonably complete understanding of the subject will not know enough about microstructure to always draw the correct conclusion.

It is my recommendation, therefore, to those foundries who wish to have control of their product by means of the microscope, to rely on the judgment of a man who has made a thorough study of the subject.

J. W. BOLTON:* The interesting and beautifully illustrated paper by Mr. Allen is a valuable contribution to the literature of gray iron microscopy. The paper was offered as an authorative treatise on the subject, for the purpose of "providing information for the practical foundryman and young metallurgist." However, the writer believes that the point of view emphasized by the author, some of the inferences as to the relative importance of certain structural formations, and the descriptions of certain components, are subject to comment. There also are a number of minor points involved in terminology and arrangement which undoubtedly will be corrected by the author, and to which no reference will be made here.

These comments are offered with constructive intent. The writer has obtained opinions from several eminent metallurgists, relative to certain points discussed herein. To these we are considerably indebted. The writer assumes personal responsibility for all statements, although he has tried to reflect accurately the opinions tendered, as well as to express his own opinion.

Point of View. The author states that "much can be done . . . by an individual possessing a little knowledge of metallurgy, and such knowledge is easy to acquire" . . . and throughout the paper gives to many the impression that the microscope is a practical tool for routine work in the hands of a semi-trained operator.

We must commend the author's enthusiasm relative to the value of metallurgical microscopy and welcome the attempt to take some of the mystery away from the microscope. However, it is our opinion that the microscope (in most cases) is primarily a research tool and unlikely to supplant our present routine methods of chemical and physical testing. The best test, of course, is a service test, and next most useful tests are those on engineering properties such as strength and hardness, supplemented by chemical and other tests to determine uniformity of product.

The more general opinion is that the misroscope is, and probably will remain, primarily a research tool with but limited routine applications.

Structural Components. The author lists the four major structural components of gray iron as ferrite, pearlite, cementite, and graphite. By definition, gray iron does not contain massive cementite. The majority of those consulted (including the writer) believe that the proper listing is graphite, pearlite, ferrite and steadite.

One metallurgist (speaking from the standpoint of low-phosphorus irons) feels that the listing should be graphite, pearlite and ferrite, since in low-phosphorus irons the steadite is present in "unimportant quantities." This, of course, is true for low-phosphorus irons, but in irons of,

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say, 70 per cent phosphorus, the steadite approximates about 7.0 per cent by volume and has an effect on fluidity, machinability and other engineering properties. Moreover, cementite sometimes occurs in chill spots, etc., which are very undesirable.

However, this part of the iron is either chilled or mottled, not true gray. Massive cementite is not found generally distributed in true gray irons, hence cannot be considered a major structural component.

Pearlite Eutectic. The author refers to pearlite both as an eutectoid and as an eutectic. In one place in particular it is referred to as an "individual grain eutectic."

All referred to agree that reference to pearlite as an eutectic is erroneous. The difference between an eutectic and an eutectoid is fundamental, as the reader can find in the texts on metallurgy. Particular attention is called to a recent issue (March 27, 1931) of *The Metallurgist*, wherein the definition of the term "eutectic" is clearly expressed and the troubles arising from its improper employment commented upon.

IMPORTANCE OF GRAPHITE

Importance of Graphite. One metallurgist states: "I believe that the amount, size and distribution of graphite flakes is of fundamental importance in determining the strength and rigidity of gray iron. I believe that it is by far the most important factor in determining these properties, and that the character of pearlite is of comparatively small importance." With quite minor qualifications, the others consulted, including the writer, agree with this statement.

However, the author emphasizes particularly the importance of the amount and character of pearlite, both in space devoted to discussion of this factor and in its primary position in the paper. In comparison, the effects of graphite would appear quite subordinate. Those particularly interested in the relationship of structure to engineering properties are urged to study the proofs of the major importance of graphite structure contained in many American papers, and particularly to the synthetic experiments of E. Thum (*Die Giesserie*, 1929), whose work definitely and directly disposes of this question for all time.

Position of Eutectic. The author states that the position of the eutectic "does not play an appreciable part in the nature of gray iron." Metallurgists consulted, including the writer, do not concur in this point of view. While the writer wants to avoid becoming unduly prolix, he wishes to point out that, as one metallurgist expressed it, "Its (the eutectic's) position at times is overlooked." In many cases the position of the eutectic is fundamental in determining the potentialities of the metal from an engineering point of view.

Combined Carbon in Eutectoid Iron. The author states that the combined carbon in pearlite (in the regular iron-carbon series) is 0.85, and in subsequent paragraphs he does not explain how the effects of graphite volume displacement, manganese, silicon, etc., very materially modify this percentage. According to the opinions rendered, effectively pearlitic matrix may be found anywhere from 0.40 to 0.90 per cent combined

carbon, according to the type of iron. Here again, abundant proofs and clear explanation are omitted because of lack of space and time.

On Phosphorus. In paragraph 121 we read, in part, "formation of an iron phosphide possessing a low freezing temperature," etc. Neither the ternary or binary eutectic (or pseudo eutectic) are iron phosphide. The first is an eutectide of cementite, iron phosphide and iron; the second, when "pure," is iron plus iron phosphide. Iron phosphides (Fe_3P, Fe_2P, etc.) are compounds, not eutectics, nor is there an eutectic of iron-phosphide and cementite. Yet the fluidity is dependent on the formation of an eutectic, according to all we can find.

Analytical reading also discloses a lack of clarity regarding the presence of pearlite and ferrite above A-3. Referring to Figs. 31 and 32 and discussion in paragraph 123, we have the phosphorus rich structure variously referred to as "island of cementite" and "phosphide eutectic." The same ambiguity appears in paragraph 127 and Fig. 33. The author refers to "cementite of phosphide eutectic" and "massive cementite" in discussion of the same structural formation. This leads to the question: Are "phosphide eutectic" and "massive cementite" synonomous?

For the sake of simplicity combined with accuracy, it appears safer to refer to *the phosphorus rich component, steadite*, rather than to employ the term "phosphide *eutectic*." The structure cannot be a true eutectic in ordinary gray irons—particularly the more usually "binary" form, which is a decomposition product of the ternary, and hence under certain conditions may contain some residual cementite, in many cases is practically free from cementite, and in low phosphorus irons quite often does not seem to retain the full amount of phosphorus required by the "pure" or synthetic binary eutectic, 89.8 Fe, 10.2 P.

Those to whom the above questions were referred agree that "phosphide eutectic and cementite" are not synonomous terms, and the majority agree it is "more desirable to refer to the phosphorus-rich component, steadite, rather than to use the term phosphide eutectic."

The writer apologizes to the author and to those who have offered many points not referred to in this discussion on account of the brevity of the discussion, but feels that it will be sufficient to indicate the major differences of opinion. The writer also is deeply indebted to the various eminent metallurgists (including Messrs. Harrington, MacKenzie, Rother and several others) whose constructive comment has been invaluable in preparation of this discussion.

It is earnestly hoped that the author will present before the Association the researches he is conducting, which will be of interest and value to our membership.

(*Continued on next page*)

WRITTEN CLOSURE BY AUTHOR

R. M. ALLEN: The author appreciates Mr. Bolton's criticisms of this paper, not only because of a realization that they were made with a constructive idea of having the subject matter correct, but also because of a feeling that there are, in the last analysis, very few, if any, serious points of difference involved.

The discussion undoubtedly was provoked by two conditions, for one of which the author is responsible; for the other, Mr. Bolton. The first was a desire that the paper be so written that those entirely unfamiliar with the subject could follow it step by step until the fundamentals of the metallurgy of cast iron were comprehended. This involved considerable deviation from the conventional method of handling the metallurgy of cast iron and the subordination of ideas and terminology that a full-fledged metallurgist might consider important.

On the other hand, had Mr. Bolton subjected the paper to a critical reading from this angle, it is probable that many, if not all, of his comments would not have been offered. It is difficult, however, for one as proficient in the subject as Mr. Bolton to do this, and the result has been a rather superficial reading of the paper on his part.

For instance, in regard to his remarks under the caption, "Structural Components," the paper does not list the major structural components of gray iron as stated by him, but names the four constituents that need to be recognized in understanding the nature of cast iron. Neither is any reference made to gray iron at all in this connection, but to cast iron only, which certainly includes both chilled and white iron.

It is difficult to conceive how one might become a proficient cast iron metallurgist without a knowledge of the nature of cementite. It is even necessary to know something about it in order to understand the nature of pearlite.

As for free cementite in gray iron, we are all in accord; the paper stresses the undesirability of any being present, but it sometimes does occur, with resultant trouble, thus necessitating some knowledge of it even on the part of a gray iron metallurgist. Frequently, also, the jobbing business of gray iron foundries requires the making of castings with chilled surfaces. Hence, a knowledge of how to produce one at will, to the required degree, is of value.

In regard to the proper listing of the components of gray iron, personally I agree with the metallurgist cited by Mr. Bolton, that steadite should not be included. While almost universally present, it favors possible future improvements in cast iron to consider it as a more or less universal impurity and class it, as in the paper, with manganese sulphide. Indeed, if we are to list the essential constituents of the ideal gray iron, they would be two only—pearlite and graphite. Possibly some day we may even modify that statement and say, pearlite and colloidal carbon.

Use of the name steadite was deliberately avoided in the paper as being one more term to confuse a beginner, but a footnote should have been included associating this name with the phosphide eutectic. This was inadvertently omitted in the final rewriting of the paper.

Pearlite is properly called an eutectoid in the paper and should al-

ways be so designated in referring to it as a constituent of steel or cast iron, in ordinary metallurgical literature. In the present paper the term "individual grain eutectic" is employed, not as a name for it but to make its nature understood by the non-metallurgist, to explain its relationship to a true (or mass) eutectic, and hence the reason for classifying it as an eutectoid (which name means "like an eutectic or partaking of the nature of an eutectic").

Mr. Bolton's comments in this connection only serve to emphasize the statement made in the paper, that the true nature of pearlite is not understood even by many metallurgists. When it is recognized that carbon atoms are free to move with respect to iron atoms in the *gamma* state, at temperatures above the transformation point (ignoring any ability of their doing so at lower temperatures), it becomes obvious that *gamma* iron and carbon under this condition can be conceived of as a fluid medium, insofar as its ability to form an eutectic is concerned. The allotropic transformation then becomes analogous to a change from a liquid to a solid state, with consequent loss of mutual solubility of the constituents in the proportions possible at the temperature of transformation and the resultant formation of an eutectic of *alpha* iron and cementite.

The essential difference between this and normal eutectics is, as implied in the paper, that the reaction responsible for it takes place within the confines of an individual austenite grain, irrespective of what is going on outside of it, rather than as a mass reaction involving a change from an obvious liquid to solid state.

While the author is familiar with the numerous discussions of the nature of pearlite in the literature, and is therefore aware that this conception of it is somewhat radical, it is felt that this view ultimately will be recognized as correct. The fact that the crystalline properties of one of the constituents (i.e., ferrite) controls the nature of the resultant structure, is entirely in accord with eutectic mixtures occurring frequently in the rocks (e.g., granophyrs), where it can be demonstrated that a similar crystallographic arrangement always exists.

Importance of Graphite. There is certainly no difference of opinion anywhere among metallurgists as to the amount and distribution of the graphite being the greatest factors in determining the strength of gray iron, and there is nothing in the author's paper to the contrary. The method employed in the development of the subject merely necessitated the position and space given to pearlite. Because of the large part played by graphite, there seems to be a common tendency to overlook the other factor—the nature of the pearlite—which also plays an important part in the ultimate qualities of the iron.

Perhaps it might simplify matters to say that, in conceiving of and producing the ideal iron, there are two major problems to solve, one positive and the other negative. The former is to obtain the strongest possible matrix, which involves the nature of pearlite and should be solved just as though there were no graphite present. The matrix of cast iron can run the entire gamut of the physical characteristics of pure iron to heat-treated eutectoid steels, and the ultimate strength will be

varied accordingly. Graphite, on the other hand, should be conceived of as involving a negative proposition, that is, how to so control the nature and amount of it that the least possible effect of its inevitable presence is noticeable.

Much progress has yet to be made along both these lines, but it is hindered by the attitude of the one cited by Mr. Bolton, that "the character of pearlite is of comparatively small importance."

Position of Eutectic. The question of the relative importance of the eutectic point in dealing with gray iron is far too involved to discuss in a limited elementary treatise on the metallurgy of cast iron such as the present paper, hence the statement to which Mr. Bolton takes exception. Furthermore, it could not have been discussed by the author without considerable reference to the conventional iron-carbon equilibrium diagram, to which he cannot subscribe when dealing with gray iron.

Combined Carbon in Eutectoid Form. Had Mr. Bolton read paragraph 119 he probably would have omitted this comment from his discussion.

On Phosphorus. Mr. Bolton's discussion of the resultant constituents due to the presence of phosphorus is interesting, and the author is substantially in accord with him on the subject. However, here also he has failed to read the paper from the standpoint of one who is being inducted into the metallurgy of cast iron for the first time.

As previously pointed out, the question of the effect of phosphorus was treated as though it is an impurity rather than an essential constituent, hence no attempt was made to go into an extended discussion of the true nature of the phosphide eutectic. From the standpoint of the beginner, it should be sufficient to associate the presence of what *appear* to be islands of cementite with phosphorus, and to intimate that there is some difference between it and cementite produced by super-cooling or insufficient silicon, and to indicate some of the ways of demonstrating the difference.

As mentioned in footnote 3 to paragraph 34, an eutectic mixture possesses a solidification temperature lower than that of the components forming it. Therefore, if iron phosphide in itself has a low freezing point, it is rather begging the question to say that the fluidity caused by phosphorus is due to the formation of the eutectic rather than to the low melting point of iron phosphide.

As a matter of fact, to be strictly correct the phraseology of the paper must be adhered to, because not all the fluidity is due to the formation of the eutectic, but in part to the phosphorus (as iron phosphide) held in solid solution in the iron surrounding the eutectic, which has its solidification temperature lowered thereby. This latter point is generally overlooked.

Point of View of the Paper. As to the point of view from which the paper was presented, and as discussed by both Mr. Bolton and Mr. Boegehold, it is intended neither as a belittling of the noble art of metallurgical research nor as an attempt to substitute the microscope as a routine inspection tool in the average foundry. Rather, it is a feeble attempt to inspire the great number of foundries to whom the microscope

has been an instrument of mystery in the past—on the basis that what one fool has done, another can do—to get busy and see what the microscope might do for them.

To be sure, there is danger in a novice making a false deduction; I have known of even expert metallurgists doing that. Nevertheless, it is probable that in no case would the effect of a false idea obtained through microscopical examination be more serious than under the old "cut and try" method where the microscope is not a factor. Moreover, there was a time when none of us knew anything about microscopical research. So let us be enthusiastic in recommending it to others, and do our part in helping them to the point where they can "go on their own."

Steel Foundry Molding Sands and Facings

By A. S. Nichols,* Chicago

Foreword

In the interest of better understanding of steel foundry facing-sand mixtures, with particular reference to characteristics and functions of the binder ingredients, the Illinois Clay Products Co. sent a questionnaire to fifty steel foundries in the Central States. Answers to the questions were returned by the executives of twenty-two foundries. These foundries have a total normal tonnage of 17,120 tons per month, and it is believed that they are representative of the district by virtue of this large figure and also because of the wide range of castings produced. In presenting this tabulation of the data received, it is not intended to draw any conclusions regarding the relative merit of materials used or practice followed in the different foundries. With the wide variety of castings made, many sand mixtures and handling procedures have been developed individually to meet specialized conditions, and comparison on such basis often is erroneous in conclusion. It is evident, however, that much progress can be made in standardization of general sand practice, and this data should be of value in indicating the points which can be studied to advantage. It is hoped that contributors and other foundries will cooperate with material and equipment producers in this manner, particularly through the established agencies of the American Foundrymen's Association committees which are working to definite ends on the general subject.

1. Table 1 details general practice data. Sixty different facing mixtures were reported, and these have been numbered. A column is provided in this table for determining the number given each facing mix used in each foundry.

* Sales Manager, Illinois Clay Products Co.

Note: This paper was presented and discussed before one of the steel sessions at the 1931 convention of the American Foundrymen's Association.

Table 1

Plant	Classification[1]	Melting equipment[2]	Avg. weight of castings, lbs.	Normal Tonnage per Month, tons				Sand Control Tests in use					Specification	Facing Nos.	Mold Drying		Sand Reclaiming Equipment				Sand Handling System					
				Total	Green	Dry	Skin dry	Strength[3]	Permeability[3]	Moisture[3]	Screen[3]	Period[4]			Hours	Temperature ° F.	Screen[3]	Suction[3]	Capacity per hour, tons	Waste per hour, tons	Magnetic separator[3]	Dust removal[3]	Mixer[5]	Distribution by[6]	To[7]	Facing distribution method[8]
1	M & J	E. F.	30	75	25		50			None			None	1, 17				None				M			
2	S and M	O.H. and E. F.	115	705	705				x		x	D	Sand	18, 32	10	600		None				M	E. B.	H and M.	Box
3	R. R.	O. H.		780	780					None			None	59, 60			x					M	Cr.	B.	Box
4	Mf. and J.	O. H.		800	300	500		x	x	x	x		None	12, 35 36, 49 50	6	850		None				M			
5	J.	E. F.	27	125	125			x	x	x			Binder	2, 3				None				M			
6	S.	E. F.	90	500	150	200	150		x				None	4, 37	6	900		None				M			
7	J.	O. H.	1587	660		660			x			D	Sand	5, 19 33, 51	10	600						M	E. B.	H. and M.	Box
8	J.	E. F.	17	550	360	135	55	x	x	x	x	H	None	6, 20 38, 39	9	550	Suction Screen	2 10	0.2 0.1			Sly	M	Cr.	H.	Box
9	J.	E. F.	500	1000	400	600			x	x			None	13, 34 52, 53 54	8 5	700 500		None			x	x	M	Con.	B. and H.	Tr. and Cr.
10	J.	O. H.	150	400	200	200		x	x	x	x		None	21, 40 41, 55	10	700		None					M			Box
11	J.	E. F.	15	180	180					None			None	7				None				Not Given			

See footnotes on page 829.

(Concluded on next page)

Table 1 (Concluded)

12	J.	E. F.	25	500				x	x	x		D	None	8				None			x		M			Box and Con.
13	J.	E. F.		300	200	100		x	x	x		W	None	9, 10 42		400	x		6		x	Vortex	M	Con., Bu., Tr.		Bu., Tr.
14	J.	O. H.	250	1850				x	x	x	x	D	None	14, 43 56	24 12	800 800	N	otGiven						NotGiven		
15	S. and M.	E. F.	22	500	375	75	50	x	x	x		D	None	22, 23 44, 45		550	x		5				M	Con.	H.	Con.
16	Mf.	E. F.	19	525	525			x	x	x		D	Sand	24					20		x	None	M	Be.	H.	Con. and Box
17	Mc.	E. F.	77	750	300	350	100	x	x	x	x		None	11, 46	8	600		x			x	x	M	Be.	B. and H.	Con. and Box
18	S.	O. H.	350	2000	1950		50						Sand	15, 16			x		10	2	x	No	P	Con.	B.	Tr.
19	J.	E. F.	8	220	200	10	10	x	x	x		D	Sand	25, 26 27, 28		400	x	x	10		x	Sly	M	Tr. and Con.	B.	Tr.
20	J.	E. F.	38	200	100		100		x	x		W	None	29, 30			x	x	100	2	x	Yes	M	Box	H.	Box
21	J.	E. F.	30		x	x	x	x	x	x		D	Sand, Clay bind.	31, 47 48	6	450	x	x	35	5	x	Yes	P	O.H.C.	B.	Box
22	S.	O. H.	600	4500								D		57, 58			x	x	3.7		x	Peco	P	Be.	B. and H.	Box

[1]M = Miscellaneous; J = Jobbing; RR = Rough Railroad; Mf = Manufacturing; S = Specialty; Mc = Machine.

[2]E. F. = Electric Furnace; O. H. = Open Hearth.

[3]The small "x" indicates that a screen, suction separator or magnetic separator was reported in use.

[4]D = Daily; H = Hourly; W = Weekly.

[5]M indicates a muller mixer; P, a pan mixer.

[6]E. B. = Electric bucket; Cr. = Crane; Con. = Conveyor; Bu. = Bucket; Tr. = Truck; Be. = Belt; O. H. C. = Overhead cars.

[7]H = Hopper; M = Molder; B = Bins.

[8]The small "x" indicates that test method shown at top of column was reported as used.

Table 2

Plant No.	Facing No.	Type of Facing*	New Sand		Old Sand		Silica Flour		Primary Binder		Secondary Binder		Auxiliary binder††	Sand Control, Tests				Cost per ton, $	Plant cost per ton of castings for all facings, $	Cost of binder per ton of sand, $	Plant cost of binder per ton of castings for all facings, $
			%	Lbs.	%	Lbs.	%	Lbs.	%	Lbs.	%	Lbs.		Perm.	Strength lbs. per sq. in.	Moisture, %	Milling, time, min.				
1	1	A	67.0	480	28	200			4.2	30	0.7	5	M				6	2.15		0.89	
5	2	A	92.6	500					7.0	38	0.4	2		165	2.0†	4.0	3	2.70	1.22	0.60	0.22
5	3	A	53.5	600	44.6	500			1.6	18	0.3	2		165	2.0†	4.0	4	1.24	1.22	0.12	0.22
6	4	A	30.3	240	60.5	480	6.3	50	2.5	20	0.4	3		250			10	1.50	2.22	0.40	0.82
7	5	A	47.2	792	47.2	792			5.0	84	0.6	2	M	200			10	1.20	2.07	0.34	0.59
8	6	A	26.8	250	69.9	650			2.7	26	0.6	2		215	1.6†	3.0	6	1.44	2.32	0.41	1.16
11	7	A	12.4	160	86.8	1120			0.4	5	0.4	5					2	0.63		0.40	
12	8	A	95.7	600					0.8	5	3.5	22		135	5.3**	3.0	9	3.54	2.25	0.46	1.00
13	9	A	32.4	400	64.8	800			0.9	12	1.9	22		175	6.0**	4.5	8	2.40	2.85	1.84	1.79
13	10	A	31.9	400	63.8	800			2.5	30	1.8	22		160	6.5**	4.5	8	2.06	2.85	1.88	1.79
17	11	A			98.8	1500			0.8	20	0.4	10	M	185	2.5†	3.5	6	0.58	2.91	0.58	1.74
4	12	B	32.4	500	64.8	1000			1.4	20	1.4	20		150	5.5**	4	15				
9	13	B	58.2	750	38.8	500			1.5	20	1.5	20		300		3	15				
14	14	B	96.2	2000					1.6	35	2.2	43		230	2.0†	3.2	6				
18	15	B	48.4	1000	48.4	1000			2.3	50	0.9	20	G				10	2.23	1.56	1.01	0.49
18	16	B	95.0	2000			0.5	10	3.5	75	1.0	20	G				10	2.97	1.56	1.06	0.49
1	17	A			98.6	340					1.4	5	M				6	0.23		0.23	
2	18	A	9.7	120	90	1050					0.3	3		210			10	0.22	1.25	0.10	0.56
7	19	A	48.2	792	48.2	792					3.6	58		206			10	1.60	2.07	0.86	0.59
8	20	A	27.6	250	71.0	650					1.4	13		225	2.0†	3.0	6	1.72	2.32	0.68	1.16
10	21	A	33.0	300	66.8	600					1.0	9		165	1.5†	4.0	6	1.44	3.85	0.35	0.44
15	22	A	33.0	300	66.0	600	0.5	5			0.5	5		200		3.0	5				
15	23	A			97.3	900	1.1	10			1.7	15		210		3.0	5				

See footnotes on page 831.

(Continued on next page)

Table 2 (Continued)

16	24	A			98.8	2500					0.2	5		200		3.0	10				
19	25	A	48.5	250	48.5	250	1.4	6			1.6	7		200	4.7**	2.25	10	1.75	3.12	0.55	2.15
19	26	A	96.0	500			1.3	6			2.7	15		230	4.0†	2.1	15	2.56	3.12	1.10	2.15
19	27	A			98.8	500					1.2	4		200	4.0†	2.3	10	1.23	3.12	0.08	2.15
19	28	A			98.9	500					1.1	3.5		135	5.0†	3.0	10	1.01	3.12	0.08	2.15
20	29	A	98.5	1200							1.5	19				2.5	5	1.64	4.98	0.53	3.13
20	30	A			98.6	1200					1.4	7				2.5	3	0.18	4.98	0.18	3.13
21	31	A	27.2	400	71.6	1200					1.2	75		175		3.5	12	2.22		1.25	
2	32	B	97.6	1260							2.4	31		220			10	2.20	1.25	0.60	0.56
7	33	B	96.4	1584							3.6	58		206			10	2.40	2.17	0.87	0.59
9	34	B	19.6	200	78.4	800					2.0	20		300		3.0	10				
4	35	C	47.1	800	47.1	800			5.8	100			M				20				
4	36	C	Core	sand																	
6	37	C	77.0	480			16.0	100	6.5	40	0.5	3		(dry) 300			10				
8	38	C	59.3	600	29.7	300	2.5	26	7.9	80	0.6	6		115	2.1†	4.0	6	2.8	2.32		
8	39	C	62.7	600	31.3	300	1.4	13	4.2	40	0.3	3		185	1.9†	3.7	6	2.20	2.32		
10	40	C	31.2	300	62.6	600			6.2	60			M		1.5†	4.0	6	1.50	3.85		
10	41	C	83.9	600			14.0	100	2.1	15			M		1.5†	4.0	8	4.40	3.85		
13	42	C	25.8	400	64.5	1000			9.7	150				150	7.0**	5.0	8		2.85		
14	43	C	14.8	325	82.0	1800	3.2	70					M	150	2.2†	4.8	5				
15	44	C	48.4	450	48.4	450	1.0	10	2.2	20				150		4.25	12				

*Types of facing are: A—Light green sand. B—Heavy green sand. C—Light dry sand. D—Heavy dry sand.
†Strength by shear method.
**Strength by compression method.
†† M—Molasses. G—Glutrin.

(Concluded on next page)

Table 2 (Concluded)

Plant No.	Facing No.	Type of Facing*	New Sand		Old Sand		Silica Flour		Primary Binder		Secondary Binder		Auxiliary binder††	Sand Control, Tests				Cost per ton, $	Plant cost per ton of castings for all facings, $	Cost of binder per ton of sand, $	Plant cost of binder per ton of castings for all facings, $
			%	Lbs.	%	Lbs.	%	Lbs.	%	Lbs.	%	Lbs.		Perm.	Strength lbs. per sq. in.	Moisture, %	Milling, time, min.				
15	45	C			96.7	900	2.2	20	1.1	10				155		4.25	12				
17	46	C	36.9	600	55.4	900			7.7	125			M				8	1.46	2.91		
21	47	C			94.1	1600	4.1	70	1.8	30			1 gal. core oil			6.5	12	1.59			
21	48	C	Core sand																		
4	49	D	78.1	1500			15.6	300	6.3	120			M				20				
4	50	D	72.7	800			27.3	300					1 gal. core oil				15				
7	51	D	74.1	1320			21.2	378	4.7	84			M	130			10	3.0	2.07		
9	52	D	18.5	200	74.1	800	1.8	20	5.6	60							15				
9	53	D	86.0	800			5.4	50	8.6	80							15				
9	54	D	92.3	1200			6.2	80	1.5	20			7 qts. core oil				10				
10	55	D	92.3	900					7.7	75			M	165		4.0	6	3.7	3.85		
14	56	D	43.3	900	50.5	1050			6.2	130			M	130	1.9†	4.6	8				
22	57	B	36.5	750	61.0	1250			2.0	45	0.4	9		178	1.75†	3.0	8				
22	58	B	77.0	1800			18.2	450	4.0	70	0.8	18		80	1.50†	3.7	13.5				
3	59	B	56.6	600	37.8	400			3.7	40	1.9	20					8	2.66	2.33		
3	60	B	92.6	1000					4.6	40	2.3	20					8	3.28	2.33	1.71	1.15

*Types of facing are: A—Light green sand. B—Heavy green sand. C—Light dry sand. D—Heavy dry sand.
†Strength by shear method.
**Strength by compression method.
†† M—Molasses. G—Glutrin.

2. Table 2 is a detailed study of sixty different facing mixtures, their ingredients, characteristics, and costs.

3. In referring to binders it was suggested that in the interest of convenience these materials be classified. Accordingly, fireclays have been termed "Primary Binders;" farinaceous binders and bentonites, "Secondary Binders;" molasses, glutrin and core oils, "Auxiliary Binders."

4. It is important to note that the cost of facing per ton of castings, or the cost of binder per ton of castings, is in each instance the figure for the entire foundry including all facing mixtures used. No foundry reported the cost per ton of castings on one facing when more than one facing was used.

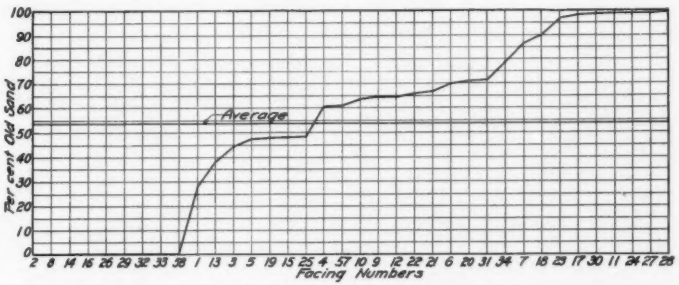

FIG. 1—PER CENT OF OLD SAND USED IN 36 GREEN-SAND FACINGS.

5. Table 3 gives the exact mix of each facing reported, unclassified. It should be noted that the term "New Sand" in almost every instance refers to silica sand of the Ottawa type.

6. Fig. 1 is illustrative of the amount of old sand used in green-sand facings. This should be of interest to gray iron and malleable foundrymen from the standpoint of sand reclamation, as clay-bonded synthetic sands in foundries of the latter type are fundamentally similar to steel foundry facing-sand mixtures.

7. Fig. 2 illustrates the permeability range in light green-sand facings, and is self-explanatory.

8. Fig. 3 shows the wide variation in milling time for facing mixtures in different groups.

9. Fig. 4 gives the average cost of new sand used per ton

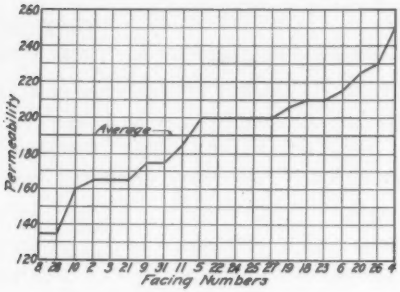

FIG. 2—PERMEABILITY OF 21 LIGHT GREEN-SAND FACINGS.

of castings (*A*) and average cost of fireclay per ton of castings used (*B*). Only those plants shown reported on these items.

10. Fig. 5 gives the average cost, per ton of castings, of farinaceous binders (*A*), bentonite (*B*), and auxiliary binders (*C*). Only those plants shown reported figures on these items.

11. Fig. 6 shows cleaning costs of 11 plants reporting this item (*A*), and average scrap losses for 14 plants reporting (*B*).

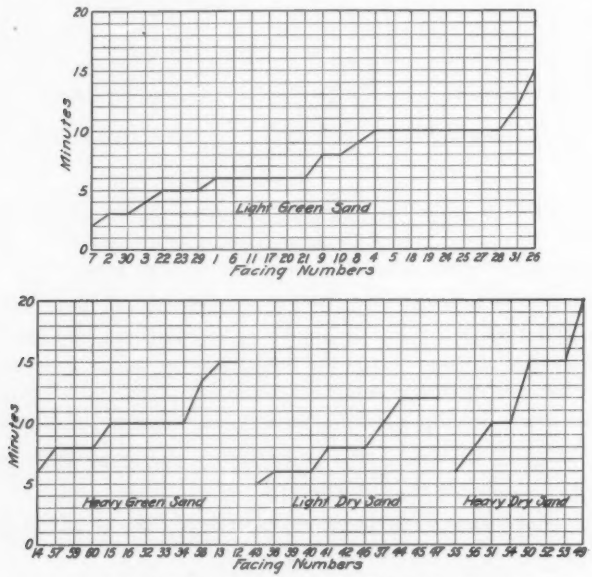

FIG. 3—MILLING TIME FOR 57 FACING SANDS.

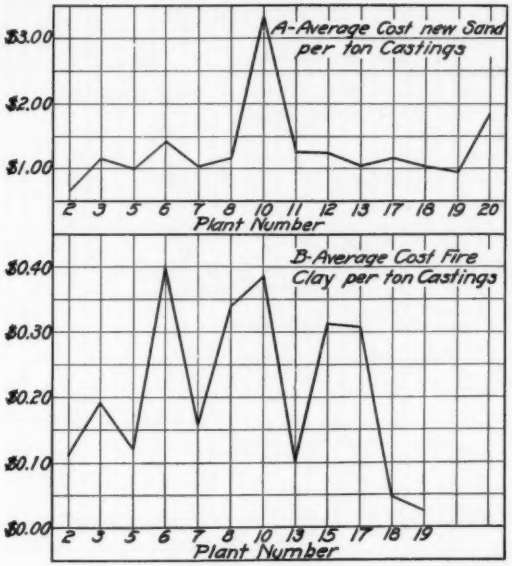

FIG. 4—AVERAGE COST OF NEW SAND AND FIRECLAY PER TON OF CASTINGS.

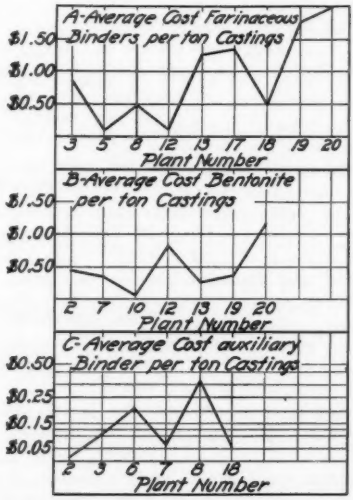

FIG. 5—AVERAGE COST OF FARINACEOUS BINDER, BENTONITE AND AUXILIARY BINDER PER TON OF CASTINGS.

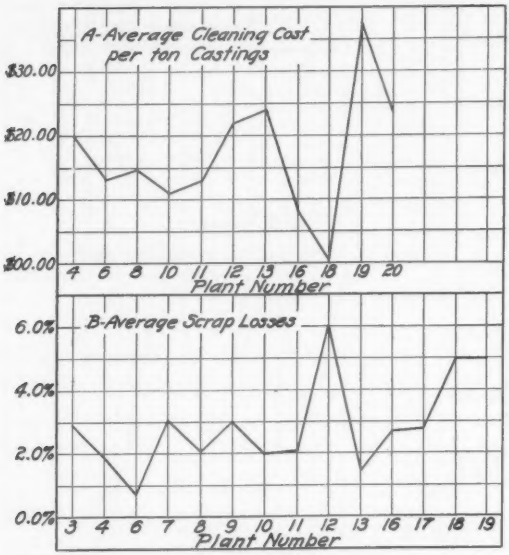

FIG. 6—AVERAGE COST OF CLEANING PER TON OF CASTINGS AND AVERAGE SCRAP LOSS.

Table 3

Facing No.	Plant	Used for	Mixture
1	1	Skin dry	480 lbs. new sand—200 lbs. old sand—30 lbs. fireclay—5 lbs. farinaceous binder—molasses water.
2	5	Light green sand	500 lbs. new sand—37 lbs. fireclay—2 lbs. farinaceous binder.
3	5	Light green sand	600 lbs. new sand—500 lbs. old sand—18 lbs. fireclay—2 lbs. farinaceous binder.
4	6	Light and medium green sand	240 lbs. new sand—480 lbs. old sand—50 lbs. silica flour—20 lbs. fireclay—3 lbs. farinaceous binder.
5	7	Light green sand	792 lbs. new sand—792 lbs old sand—84 lbs. fireclay—2 gal. molasses water.
6	8	Green sand to 200 lbs.	250 lbs. new sand—650 lbs. old sand—26 lbs. fireclay—2 lbs. farinaceous binder.
7	11	General green sand	160 lbs. new sand—1120 lbs. old sand—5 lbs. fireclay—5 lbs. bentonite.

(Continued on next page)

Table 3 (Continued)

Facing No.	Plant	Used for	Mixture
8	12	Light green sand	600 lbs. new sand—5 lbs. fireclay—15 lbs. bentonite—5 lbs. farinaceous binder.
9	13	Ordinary green sand molding	400 lbs. new sand—800 lbs. old sand—12 lbs. fireclay—18 lbs. farinaceous binder.
10	13	Old mix (obsolete)	400 lbs. new sand—800 lbs. old sand—30 lbs. fireclay—7 lbs. bentonite—15 lbs. farinaceous binder.
11	17	Light green sand	1500 lbs. old sand—20 lbs. fireclay—10 lbs. farinaceous binder—1 gal. molasses water.
12	4	General green sand	500 lbs. new sand—1000 lbs. old sand—20 lbs. fireclay—20 lbs. farinaceous binder.
13	9	General molding air dry 3-4 hrs.	750 lbs. new sand—500 lbs. old sand—20 lbs. fireclay—20 lbs. farinaceous binder.
14	14	Heavy green sand	2000 lbs. new sand—21 lbs. fireclay—40 lbs. bentonite—3 lbs. farinaceous binder.
15	18	Heavy green sand	1000 lbs. new sand—1000 lbs. old sand—50 lbs. fireclay—20 lbs. farinaceous binder—1/2 gal. glutrin.
16	18	Heavy green sand	2000 lbs. new sand—10 lbs. silica flour—75 lbs. fireclay—20 lbs. farinaceous binder—1/2 gal. glutrin.
17	1	Bench sand	340 lbs. old sand—5 lbs. bentonite.
18	2	Light green sand	120 lbs. new sand—1050 lbs. old sand—3 lbs. bentonite.
19	7	Light green sand	792 lbs. new sand—792 lbs. old sand—58 lbs. bentonite.
20	8	1/2 to 150 lbs.	250 lbs. new sand—650 lbs. old sand—10 lbs. bentonite—3 lbs. farinaceous binder.
21	10	All miscellaneous green sand	300 lbs. new sand—600 lbs. old sand—7 lbs. bentonite—2 lbs. farinaceous binder.
22	15	Light green sand	300 lbs. new sand—600 lbs. old sand—5 lbs. of silica flour—5 lbs. of bentonite.
23	15	Light green sand	900 lbs. new sand—10 lbs. silica flour—10 lbs. bentonite—5 lbs. farinaceous binder.
24	16	Facing and heap sand, light green sand	2500 lbs. new sand—5 lbs. bentonite.

(Continued on next page)

Table 3 (Continued)

Facing No.	Plant	Used for	Mixture
25	19	General green sand	*250 lbs. new sand—250 lbs. old sand—6 lbs. silica flour—3½ lbs. bentonite—3 lbs. farinaceous binder.
26	19	Cast gear teeth	†500 lbs. new sand—6 lbs. silica flour—9 lbs. bentonite—6 lbs. farinaceous binder.
27	19	Special casting, light green sand	500 lbs. old sand—4 lbs. bentonite.
28	19	Small casting, thin-section green sand	500 lbs. old sand—2 lbs. bentonite—1½ lbs. farinaceous binder.
29	20	Light green sand	1200 lbs. new sand—7 lbs. bentonite—12 lbs. farinaceous binder.
30	20	Light green sand	1200 lbs. old sand—7 lbs. bentonite.
31	21	General green sand and skin dry	400 lbs. new sand—1200 lbs. old sand—75 lbs. bentonite.
32	2	Heavy green sand	1260 lbs. new sand—31 lbs. bentonite.
33	7	Heavy green sand	1584 lbs. new sand—58 lbs. bentonite.
34	9	General green sand	200 lbs. new sand—800 lbs. old sand—20 lbs. farinaceous binder.
35	4	General medium and light dry sand	800 lbs. new sand—800 lbs. old sand—100 lbs. fireclay—molasses water.
36	4	Light work, dry sand	800 lbs. new sand—10 lbs. farinaceous binder—1 gal. core oil.
37	6	Medium and heavy casting, dry sand	480 lbs. new sand—100 lbs. silica flour—40 lbs. fireclay—3 lbs. farinaceous binder.
38	8	General dry sand	600 lbs. new sand—300 lbs. old sand—26 lbs. silica flour—80 lbs. fireclay—6 lbs. core binder.
39	8	Air dry for floor work	600 lbs. new sand—300 lbs. old sand—13 lbs. silica flour—40 lbs. fireclay—3 lbs. farinaceous binder.
40	10	Light and miscellaneous dry sand	300 lbs. new sand—600 lbs. old sand—60 lbs. fireclay—1/2 gal. molasses water.
41	10	Gear teeth work	600 lbs. new sand—100 lbs. silica flour—15 lbs. fireclay—2 qts. molasses water.
42	13	Large dry sand molds	400 lbs. new sand—1000 lbs. old sand—150 lbs. fireclay.
43	14	Light dry sand	325 lbs. new sand—1800 lbs. old sand—70 lbs. fireclay.

* Mississippi River sand.
† One-half Mississippi River sand.

(Concluded on next page)

Table 3 (Concluded)

Facing No.	Plant	Used for	Mixture
44	15	Light dry sand	450 lbs. new sand—450 lbs. old sand—10 lbs. silica flour—20 lbs. fireclay.
45	15	Light dry sand	900 lbs. old sand—20 lbs. silica flour—10 lbs. fireclay.
46	17	Light dry sand	600 lbs. new sand—900 lbs. old sand—125 lbs. fireclay—3 gal. molasses water.
47	21	General dry sand	1600 lbs. old sand—70 lbs. silica flour—30 lbs. fireclay—1 gal, core oil.
48	21	General core work	650 lbs. old sand—2 lbs. farinaceous binder—3 qts. core oil.
49	4	General heavy, dry sand	1500 lbs. new sand—300 lbs. silica flour—120 lbs. fireclay—molasses water.
50	4	Heavy work, dry sand	800 lbs. new sand—300 lbs. silica flour—1 gal. core oil.
51	7	Heavy dry sand	1320 lbs. new sand—378 lbs. silica flour—84 lbs. fireclay—molasses water.
52	9	Manganese molding, dry sand	200 lbs. new sand—800 lbs. old sand—20 lbs. silica flour—60 lbs. fireclay.
53	9	Carbon steel facing, dry sand	800 lbs. new sand—50 lbs. silica flour—80 lbs. fireclay.
54	9	Core sand	1200 lbs. new sand—80 lbs. silica flour—20 lbs. fireclay—7 qts. core oil.
55	10	Heavy and special machine, dry sand	900 lbs. new sand—75 lbs. fireclay—1/2 gal. molasses water.
56	14	Heavy dry sand	900 lbs. new sand—1050 lbs. old sand—130 lbs. fireclay—molasses water.
57	22	Heavy green sand	750 lbs. new sand—1250 lbs. old sand—45 lbs. fireclay—5 lbs. bentonite—4 lbs. farinaceous binder.
58	22	Heavy green sand	1800 lbs. new sand—450 lbs. silica flour—70 lbs. fireclay—18 lbs. farinaceous binder.
59	3	Heavy green sand	600 lbs. new sand—400 lbs. old sand—40 lbs. fireclay—20 lbs. farinaceous binder.
60	3	Heavy green sand	1000 lbs. new sand—40 lbs. fireclay—20 lbs. farinaceous binder.

(*Discussion on next page*)

DISCUSSION

ORAL DISCUSSION

A. S. NICHOLS: I would like to state briefly a few items brought up by various contributors, which may be of interest. Some foundries had difficulty in obtaining a good cost on the labor of milling. They paid their men by the batch and, on checking up, found that the batch often was short weighted. They placed automatic recording devices on the mixers, which registered in the foundry office the weight of each batch milled. This may not be and probably is not new to many foundrymen, but I had not seen it before and felt it worth while to report.

In view of the very interesting discussion brought up at the steel session by Mr. Melmoth on the question of backing sand, and also the very proper importance attached to that by both Mr. Cole and Mr. Batty, I would like to mention that figures on the characteristics of backing sand were very rare in the filled-out questionnaires which were contributed for this paper. A number of plants which regularly test their facing sands may also test their backing sands, but they did not so report on this questionnaire.

I might also mention a wide variation in the unit of measure reported. We had everything reported from shovels and wheelbarrows on up; in fact, every sort of container used. This may lead to error in making up batches, although in preparing this paper, effort was made to ascertain definite quantities used.

One foundry had a practice which they found very worth while, consisting of a weekly meeting for the discussion of sand practice as related to individual jobs. A prominent foundry reports this practice to be very helpful. It has been carried on for a number of years, a record being kept of each meeting. I know of no place where more practical data on sand are to be found than in the files this company has on the reports of their sand meetings.

Another observation, which I am sure will be of interest, is the experience of a steel foundry in controlling their sand by A.F.A. tests. They adopted specifications for strength, moisture and permeability of their facing mixtures, giving maximum and minimum limits. As a batch of facing sand is made, it is dumped into a box and immediately tested, at a cost of but a few cents (accurately determined). If the sand does not fall within maximum and minimum limits as covered by the specifications for the intended job, the facing is dumped; and, while that sand may have cost them five dollars or so, they do not make several hundred dollars worth of castings with it, only to scrap them.

In fact, on a production job in that foundry covering about 250 castings daily, weighing above 200 lbs., their losses following this method, over a period of more than a year with which I am familiar, fell below one-half of one per cent.

The form of questionnaire which was submitted to 50 foundries, asking them to contribute information, was developed by L. E. Everett, formerly foundry engineer for the Illinois Clay Products Co. and now steel foundry superintendent for the Stockham Pipe & Fittings Co., Bir-

mingham, Ala. I wish to give Mr. Everett credit for the very satisfactory way in which that questionnaire form was prepared.

CHAIRMAN R. A. BULL:[1] I feel that the author has done a particularly good job in reporting such a mass of information. It probably will surprise many of us to observe such discrepancies in practice. It shows there is plenty of opportunity for general agreement on sand practice.

However, local conditions of various kinds, including the variability of the materials employed, have a good deal to do with such factors as permeability, mulling time, etc. One man's mixer may, within a period of five minutes, produce a much more effective result than another man's mixer.

This may hold, if the mixers are furnished by the same concern and are exactly of the same type, depending in no small degree on the maintenance of the mixer itself. I like to see mullers and other pieces of equipment kept in good condition. Details of this sort may serve to explain some of the discrepancies noted.

It occurred to me, when I was talking with Mr. Nichols some weeks ago about this information, that cleaning costs are very difficult to use as a basis for comparison, because the cleaning costs in many a foundry which attempts to maintain an exact standard as to surface appearance, will spread all over the map, depending on the nature of the castings that happen to be made from day to day. Of course, that is chiefly due to the difference in design, but we must keep this factor in mind in attempting to gage the ultimate cost of any particular facing mixture.

A. F. BURTT:[2] We contributed to this paper, and when Mr. Nichols brought it out to us we went over it carefully and compared it with the various shops that reported. We got some very valuable data.

In reporting our sand mixtures, we took two representative sand mixtures, first, our squeezer sand, which is all for small work—green sand. For dry sand we used our railroad floor facing.

After getting this paper from Mr. Nichols, I drew up an average for all the various items and compared our Chicago Heights plant with them. We took the weights of the castings, our average weight being only 77 lbs. Drying time of molds average 9½ hours, as compared with our time of 8 hours. Drying temperature averaged 625 degs. Fahr., compared with our average of 600 degs. Fahr. The cost of all facings averaged $2.53, compared with our cost of $2.91, which is not a true representative cost of all our facings—we simply used two representative sand mixtures.

Cost of binder per ton of casting averaged $1.11, whereas ours was $1.74. Per cent of old sand used in green-sand facings averaged 54 per cent; we average 98.8 per cent, because we use all old sand on our snap work. Permeability of new sand averaged 185, and ours was reported the same. Milling time of green sand averaged 7.4 minutes, and ours, 6 minutes; dry sand milling time, 9.7 minutes, against our average of 8 minutes. Cost of new sand per ton of castings averaged $1.35, compared with our average of $1.08. Cost of fireclay per ton of castings averaged 21 cents; ours was 31 cents. Cost of farinaceous binders per ton of castings average 92½ cents; ours, $1.27. Average scrap loss was 2.6; ours was 2.8.

[1] Director, Electric Steel Founders' Research Group, Chicago.

[2] Safety Director, American Manganese Steel Co., Chicago Heights, Ill.

A. S. NICHOLS: Because of my experiences in getting people to contribute data for this paper, I wish to make public acknowledgment of the appreciation which I am sure I have and others must have for the courtesy and kindness of Mr. Burtt and his company in giving us these costs. It has been very difficult to get such figures.

CHAIRMAN R. A. BULL: I am sure everybody shares that sense of appreciation. The data presented by Mr. Nichols are so comprehensive that they need to be studied and particularly compared with each man's special practice. In other words, it is extremely useful information for reference purposes. I have no doubt the practices that are reported will stimulate a good many foundrymen to make changes in their own practice —probably, in many cases, with very beneficial results.

A. S. NICHOLS: I might mention in this connection that, unless other agencies care to take the matter over, we hope next year to continue the progress which may have been made in standardization.

Deep Etching of Brass Applied to Gating Problems

By R. W. Parsons,* Mansfield, Ohio.

Abstract

Deep etching of brass castings here is shown as applied to determination of the best method for gating castings. Defects on original gating are shown. Changing sizes of test bars brought out a definite relationship between length of bar and diameter to obtain sound castings. Pouring temperature also is shown to have a definite relation to the physical properties obtained. Causes of leaks resulting in defective globe-valve castings were investigated by deep etching; re-gating reduced the losses to a minimum. Limits to the application of deep-etch testing are given.

Introduction

1. Last year, at the convention in Cleveland, a paper was presented regarding the application of the deep-etch test to brass.[1] The method was given in detail with numerous illustrations outlining the several applications for this type of examination. The object of this second paper is to present briefly a few specific instances wherein the test has been successfully employed as an aid to establishing satisfactory gating.

2. Deep etching of brass is accomplished by subjecting the specimen, often rough ground to eliminate saw marks and present a fairly smooth surface, to the action of concentrated commercial nitric acid for a period of seven to eight minutes—depending upon the size of the piece and the amount of acid used in relation to the surface of the specimen. For etching brasses containing tin,

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[1] *Deep-Etch Test of Brass*, by W. F. Graham and L. A. Melsse. A. F. A Transactions and Bulletin, Feb., 1931, p. 810.

Note: This paper was presented and discussed before one of the nonferrous sessions at the 1931 convention of the American Foundrymen's Association.

10 per cent of commercial hydrochloric acid usually is added to keep the tin oxide in solution.

DEVELOPMENT OF A TENSILE BAR GATING

3. Some few years ago a considerable number of tensile test bars were required to investigate the effect of corrosion on the physical properties of various alloys subjected to the action of locomotive smoke.[2] In this connection it was desirable that all specimens be cast from the same ladle of metal so as to introduce as few variables as possible.

4. With the standard A. S. T. M. tensile bar, which required about 10 lbs. of metal to produce one specimen, several heats and a multitude of molds would have been necessary for the number of bars desired. In order to simplify the molding and melting, a gating was developed, without recourse to the etch test, which gave three bars per mold and sufficient molds to the ladle so that the entire lot of a given composition could be poured from one small heat.

5. The layout of this gating is shown by the sketch of Fig. 1. The mold was poured uphill at about seven degrees to the horizontal.

6. After this gating had served the purpose for which it was developed, it was adopted for routine checking, inasmuch as it offered several advantages, namely, three bars instead of one from a somewhat smaller quantity of metal, no cores needed, and less machining required to prepare a specimen for test. The center bar was removed later when it was felt that duplicate bars would be sufficient for regular testing.

7. The physical properties obtained from the above tensile specimens compared favorably with those from the A. S. T. M. bar, but it soon became apparent that something was amiss. Depending upon where the bars fractured with respect to the center of the gage length, porosity was in evidence or the fractures were sound, as the case might be.

8. Defects were revealed by etching the section (Fig. 2-*A*), although the pronounced shrinkage cavity was visible before etching (Fig. 2-*B*). This information could have been obtained from

[2] "Corrosion of Alloys Subjected to the Action of Locomotive Smoke," by F. L. Wolf. A. I M. E. *Technical Publication No.* 293, *Class E,* Institute of Metals, No. 104.

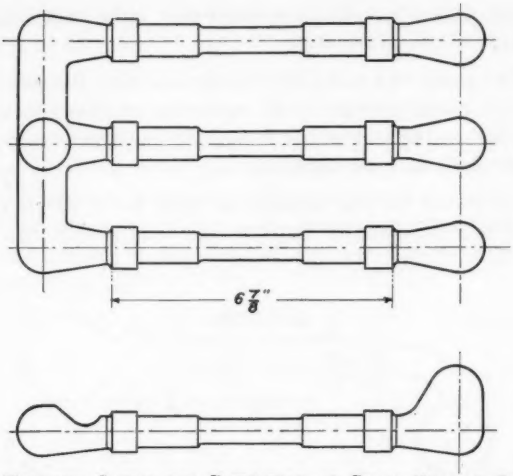

FIG. 1—MULTIPLE GATING FOR PRODUCTION OF BRASS TENSILE SPECIMENS. CONSISTED OF WOODEN PATTERN MOUNTED ON MAHOGANY BOARD. MOLDS MADE IN 9 BY 14 INCH SNAP FLASK AND POURED UPHILL AT ABOUT SEVEN DEGREES TO HORIZONTAL. OVER-ALL LENGTH OF SPECIMEN GREATER THAN A. S. T. M. BAR AND CONSIDERABLY LESS MACHINING REQUIRED SINCE ENDS WERE CAST TO FIT HOLDERS OF TENSILE MACHINE.

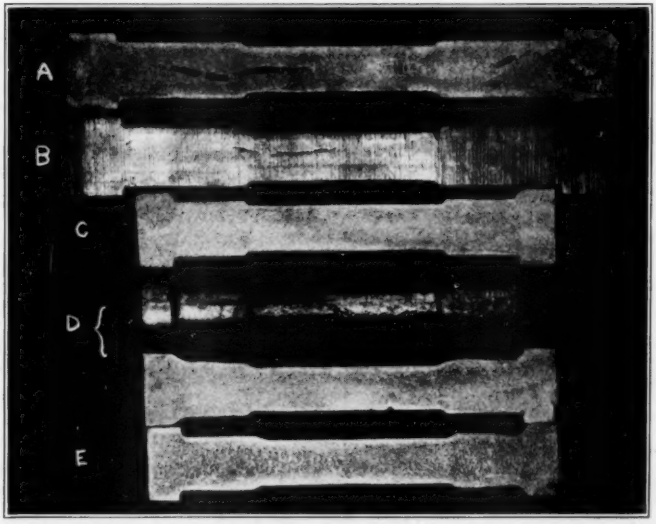

FIG. 2—ETCHED SECTIONS OF TENSILE BARS PRODUCED FROM VARIOUS GATINGS. GATED ENDS ARE AT RIGHT IN ALL CASES.

fractures as well, but a whole series would have been required to furnish equivalent information.

9. The gated end was identified by marking the pattern with a stencil. Several changes were made in an effort to eliminate the shrinkage at the end of the gage length—larger risers, poured uphill, downhill, and *ad infinitum*.

10. Working on the assumption that for a given cross-section there is some definite limit to the length that can be cast

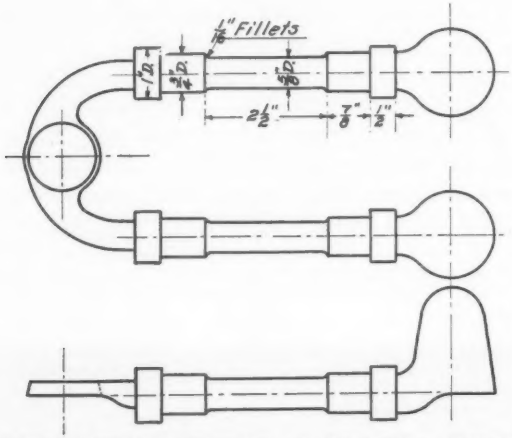

FIG. 3—TENSILE TEST BAR SHORTENED AND RE-GATED TO PRODUCE SOUND SPECIMENS AS SHOWN BY DEEP-ETCH TEST. ENDS OUTSIDE THE GAGE LENGTH ARE THE MINIMUM LENGTH WHICH FIT THE HOLDERS OF TENSILE MACHINE, AND TWO BARS ARE PRODUCED FROM 4¾ LBS. OF METAL. MOLD IS POURED UPHILL AT ABOUT SEVEN DEGREES TO HORIZONTAL. LITTLE MACHINING IS NEEDED TO PREPARE SPECIMENS.

sound, the bar was shortened to give the minimum length, outside the gage length, which would fit the holders of the tensile machine. With the shorter bar and a layout quite similar to the first tensile bar gating (Fig. 1), a sound specimen was obtained (Fig. 2-*C*).

11. In this second gating (Fig. 3), the risers were set closer to the ends of the bars and the gates were considerably smaller —less than five pounds of metal were required to pour one mold and produce two bars. The uphill pouring gave a cleaner surface than was obtained by pouring downhill with the risers next the

sprue, although both methods gave equally sound castings as shown by the deep etch.

12. Pouring the bar level, with the sprue acting as the only feeder, served satisfactorily as far as soundness of the etched section was concerned (Fig. 2-*D*), but with this method the gate had to be left wide open and the bars were so dirty that they had to be machined undersize. With the test bar cast parallel to a runner on which two risers were placed so as to feed into the sides of the collars at the ends of the bar, the feeding was not satisfactory (Fig. 2-*E*).

13. The pouring temperature is, of course, important in the

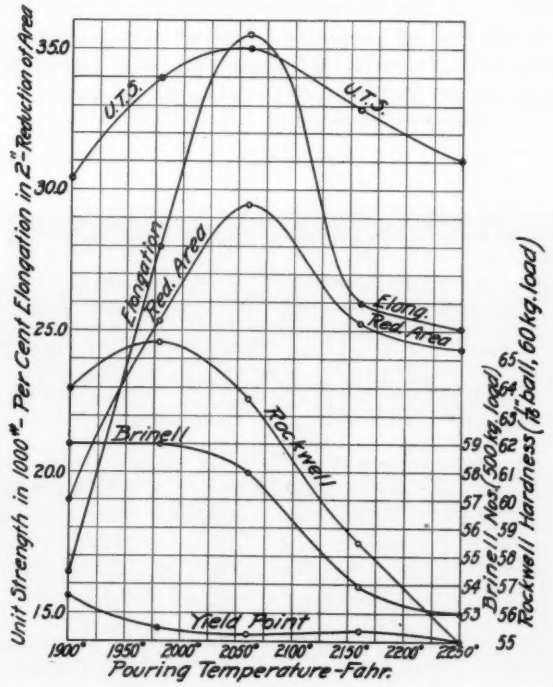

FIG. 4—SHOWING EFFECT OF POURING TEMPERATURE ON PHYSICAL PROPERTIES OF ALLOY CONTAINING COPPER 84.64 PER CENT, TIN 3.38, LEAD 3.14, ZINC 8.84. TENSILE SPECIMEN USED IS FIG. 3 AND CURVES SHOW OPTIMUM POURING TEMPERATURE TO BE 2060 DEGS. FAHR. FOR THE GATING AND ALLOY.

same way that each job in the foundry has its own proper pouring temperature. The chart of Fig. 4, plotted from five points, shows how the physical properties vary with pouring temperature with the second tensile bar gating (Fig. 3). The same alloy and a fixed pouring temperature were used in all experiments with the gating of test pieces.

IMPROVEMENT OF AN IMPACT BAR

14. Etched sections (Fig. 5), from a mold (12 castings) of Izod impact specimens of the three notch type, show that the risers are not adequate to properly feed the castings. The surfaces of the castings were usually rather dirty, so no attempt was made to increase the size of the gates in the above.

15. Again working on the theory that there is a limit to the length which can be cast sound with a given cross-section, a mold was stopped off so that the castings were shortened to the length of a single-notch Izod specimen. An improvement was brought about by decreasing the length, but the etched specimens still showed considerable porosity.

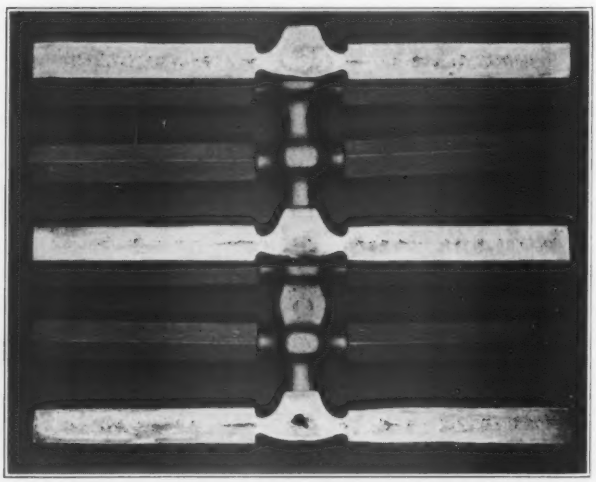

FIG. 5—SHOWING PORTION OF THE ORIGINAL GATING OF 12 IZOD IMPACT SPECIMENS. ALTERNATE PAIRS OF BARS ARE ETCHED TO REVEAL DEFECTS. THE SPRUE WHICH WAS AT THE BOTTOM, AND THE PAIR OF BARS NEXT THE SPRUE, ARE NOT SHOWN.

16. Since 12 specimens were many more than were needed for the usual tests, a gating of four pieces was made, similar to the second tensile bar gating (Fig. 3), and poured uphill as before. With the gates sufficiently thin, so that the casting did not feed back into the gate, good results were obtained (Fig. 6-*A*), while with a thicker gate (Fig. 6-*B*) the casting fed back into the gate.

17. The risers of the tensile and impact bars (Fig. 6, *A* and *B*) do not show a pronounced shrinkage cavity because, to obtain the maximum physical values, the pouring temperatures are low. The fact that these are "dead" risers also has considerable influence since some "pipe" would be developed, even at the low temperature, if the risers were next the sprue. At higher temperatures, the risers on both types of test bars (Figs. 3 and 6) develop moderate shrinkage cavities.

18. A riser which exhibits a large shrinkage cavity is shown in Fig. 6, *C* and *D*. Incidentally, this is of the same alloy and poured at practically the same temperature as the test bars. It

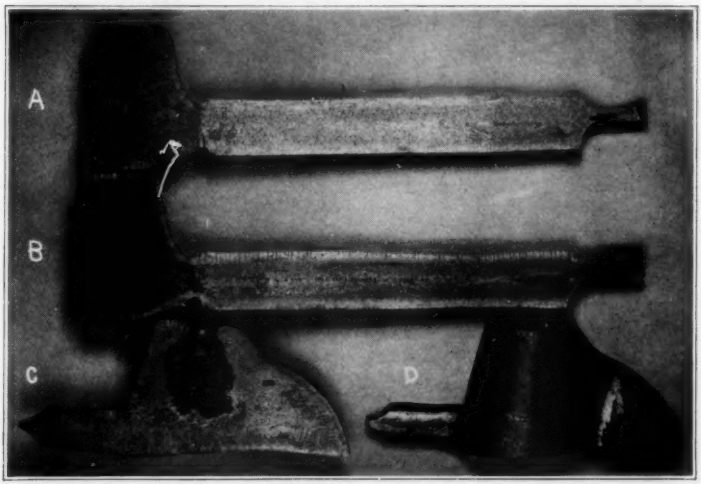

Fig. 6—Etched Sections of Izod Impact Bars, Showing Improvement in Structure Obtained After Re-Gating. In *C* and *D*, Etched Section and Outside Contour of a Riser Which Functions Efficiently Are Shown.

is interesting to note to what extent the "hot spot" inclines to the right (Fig. 6-*C*), which is in the direction of feeding.

LEAK LOSSES REDUCED BY RE-GATING

19. A globe-valve body with a drain cock attached (Fig. 7, *A* and *B*) illustrates an application of greater interest to foundrymen than the production of test bars. These castings were produced on a Berkshire machine where both cope and drag were made from a single plate. This necessitated a rollover of the drag side so that the drains on one side of the center runner were in the cope (Fig. 7-*A*) and those on the opposite side of the runner in the drag side of the mold (Fig. 7-*B*).

20. It will be seen that, with the drain in the drag (Fig. 7-*B*), the adjacent thin section has partially fed the drain, leaving a considerable area of shrinkage, and it was found that in 80 per cent of the leakers the drains had been cast in this position. Re-gating this pattern with all the drains in the cope reduced the average leak losses from 5 per cent to 1 per cent.

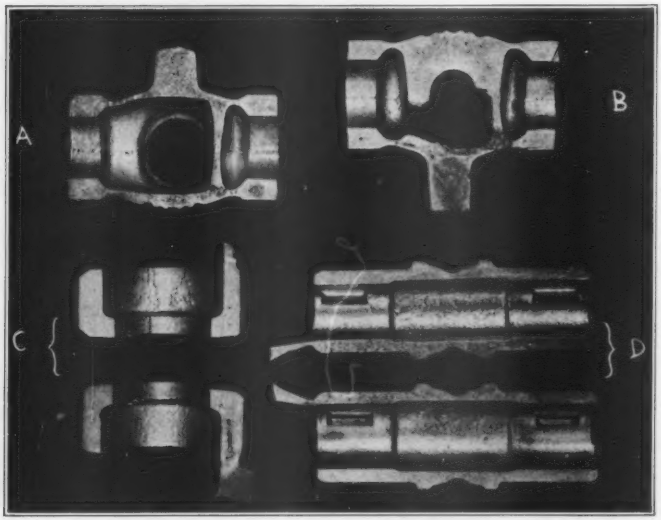

FIG. 7—SHOWING INFLUENCE OF GATING ON SOUNDNESS OF SMALL GLOBE-VALVE BODY. GATE IS TOWARD CENTER IN EACH CASE. *C* AND *D* ILLUSTRATE DISTRIBUTION OF DEFECTS IN DISSIMILAR CASTINGS.

Limits to Application of the Test

21. In connection with examination of light brass castings, it might be well to point out that gating is such a vital factor as regards the quality of etched sections that it often is difficult to discern any connection between the results of the etch and other factors which may be under investigation, unless the gating be kept constant through use of a single pattern.

22. As an example of the above, it was found that etched sections of dissimilar castings, one casting from each heat, taken over a period of weeks, showed that the samples from certain patterns were good with few exceptions, while those from other patterns were poor regardless of the character of the material charged into the furnace. This condition held even though the castings were from the same heat of metal.

23. Thus, whatever information existed regarding metal conditions—such as comparisons of ingot quality, furnace practice, or ingot *vs.* prime metals—this information was obscured by the lack of uniformity in the character of the specimens.

24. Etched sections from two different patterns, which were poured in succession from the same ladle of metal and sectioned through the gate in both cases, show different distribution of shrinkage and variance in quality as shown by the etch test (Fig. 7, *C* and *D*).

25. One casting (Fig. 7-*C*) shows a shrinkage cavity localized at the gate and exhibits an excellent surface throughout the remainder of the section, while in the other casting (Fig. 7-*D*) the shrinkage is pretty well distributed around the circumference. Thus, sections made at random through these particular castings would create the impression that the former, with the localized defect (Fig. 7-*C*), was the better metal.

Conclusions

26. It has been attempted to illustrate, by relating several instances, that the deep-etch test can be useful in connection with problems of gating which have to do with the production of sound castings. Such phases of gating as elimination of dirty surface and excessive mis-runs, of course, require other methods of attack.

27. In collecting information on the internal soundness of

red-brass castings, the deep-etch test offers certain advantages over the older method of merely fracturing the piece, in that sections can be made longitudinally and through heavy sections which would be difficult to fracture. A clearer and more complete picture of the condition is obtained through the greater portion subjected to examination, and the chances for detection of defects are somewhat greater with the etched sections.

28. As is true of any valuable tool, it is apparent that there are certain limits to be placed on the application of the deep-etch test to foundry problems in general. It is practically impossible to draw any conclusions as regards metal conditions from etched sections of dissimilar castings, since gating plays such an important part in determining the quality which the etch test reveals.

ACKNOWLEDGMENT

29. The author is indebted to members of the Technical Department of the Ohio Brass Co., for criticism and aid in preparation of specimens, and particularly to L. A. Meisse, who prepared the photographs.

DISCUSSION

ORAL DISCUSSION

W. F. GRAHAM :[1] As far as the deep-etching test goes as presented in this paper, and the practical application Mr. Parsons has made of it, I have very little comment. With regard to the design of the test bar itself, although my recent experience has shown me that there is much to be done about test bar design, and while Mr. Parsons has, by this test, improved the previous design of test bar with which he has been working, I still think that a great deal more can be done to improve the soundness of that bar and lead to the development of a standard bar for various alloys which will give us more uniform physical results.

[1] Technical Director, Caskey Brass & Bronze Works, Inc., Philadelphia.

CHAIRMAN J. W. BOLTON:[2] I may say that our company makes quite a few pressure castings. We have been using this test method successfully for quite a few years in the study of the test bar and of the castings. Perhaps we have also stressed in our own work a little further the study of the density of the metal in the gate and risers. This has been covered to some degree in the paper.

Ordinary bronze, apparently, shrinks quite a bit more than we are accustomed to think, and when we get into pressure work we are machining off the outside and inside, throwing away some of the better part of the material in order to be sure of the soundness of the interior. This test is very useful in determining the effectiveness of the feeding of risers and how far it is necessary to go with risers.

E. F. HESS:[3] We have made several different kinds of test bars and we found that we had increased the tensile strength a great deal through the shape of the bar. The first test bars we poured straight up and down with quite a large riser on the top, which we machined down to size. Where we machined off the outside surface, the test bar was materially weaker than when we cast it to a definite shape and took off just enough metal to clean it up and bring it to size.

R. W. PARSONS: There is something I would like to add in this connection. With this particular gating, if the bar is not machined off but is pulled as cast, the skin effect is so pronounced as to partially offset the effect of pouring temperature.

Another thing about this particular gating is that, although one can get higher strengths by other methods, this method is more representative of the usual casting condition than are some of the others.

FRED L. WOLF:[4] I recently saw the results of a test that can be considered as a preliminary one, not final, in which a comparison was made of bars of different types. Considering one particular type of bar, the pouring temperature ranging from 2150 to 2300, very little difference in physical properties was noticed, while with the standard bars, variations in the pouring temperature made quite a little difference in physical properties.

CHAIRMAN J. W. BOLTON: In working with a bar somewhat like the one on which Mr. Wolf's organization is working at the present time, we have found that, materials being sound, the pouring temperature is not so important as gating, rather generous risers, etc. Also, in machining the bar, the results as between machined bars and unmachined bars were not very great—less than five per cent over a long period of time—when we ran parallel tests.

MEMBER: Regarding the casting (Fig. 7, *A* and *B*), when the position was reversed and the casting made with the drain in the cope, was a spongy condition encountered in the drain, offsetting the advantage of casting in that way?

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[2] Metallurgist, The Lunkenheimer Co., Cincinnati.
[3] Foundry Superintendent, Ohio Injector Co., Wadsworth, Ohio.
[4] Chief Engineer and Technical Superintendent, Ohio Brass Co., Mansfield, Ohio.

R. W. PARSONS: That is true; there is no provision to feed the drain. The metal just flows in and takes a set. Generally, the pipe localizes itself in the middle of the drain and is tapped out.

MEMBER: My idea was that it would be spongy. The castings must be poured relatively warm; it is a rather thin section.

R. W. PARSONS: The pouring temperature was about 2120 degs. Fahr.

H. M. ST. JOHN:[5] A point I would like to comment on is the effect of pouring temperature on the physical properties. It seems to me that we are in a little danger of forgetting the fundamental conditions.

As I see it, the maximum physical properties in a test bar or any other piece of metal require, first, that the casting must be sound—that is, free from cracks or incipient shrinkage; and, second, that the grain must be as close as possible. Obviously, that is not a function merely of the temperature but also of the gating—the way in which the casting is fed.

I still believe that if the casting is so gated that a sound casting is obtained in every test made, then the lowest pouring temperature naturally will give the finest grain and the maximum physical properties.

It may be that it would be possible to reach a wrong conclusion from Mr. Parson's curves, the idea being that the metal can be poured either too hot or too cold to get maximum physical properties. It can be poured so cold that the casting is defective; but, aside from this, if it is poured hot enough that a sound casting is obtained, I still think that the lowest pouring temperature will give the best physical properties. That is open to investigation, but until investigation shows otherwise, I believe we have a right to believe this.

Another point is in connection with the use of test bars in general. I suppose all of us have certain views on this subject. I think it is obvious that a test bar can be poured attached to a casting; the test bar can be perfectly good and the casting bad, or the casting can be good and the test bar bad.

The whole matter of test bars, it appears to me, is one which should receive a thorough housecleaning. I do not know who should do it, but it is overdue.

MEMBER: Has anyone had similar experience to ours with test bars attached to castings—large, manganese-bronze castings? Sometimes in the lower section of the bar we find a very coarse crystalline structure. Wedges will be cast vertically and the test bar also vertical, yet unaccountably we get very coarse crystalline structures in the lower part of the bar, whereas the upper part will be quite close grained. This test bar is cast flat against the casting.

J. E. CROWN:[6] I have cast some coupon test bars of manganese bronze, but I cannot say that I have run into that condition of large crystalline structures in one section of the bar as compared to a finer crystalline structure in the upper section.

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[5] Chief Metallurgist, Detroit Lubricator Co., Detroit.

[6] Master Mechanic, Foundries, U. S. Naval Gun Factory, Washington.

The greatest difficulty I have run into in casting this type of bar—the manganese-bronze bar, of course, being just a flat bar, rather wide, an inch thick, attached to the casting—is that it acts like a sewer. All of the dirt and scurf that is going ahead of the metal drops down into the test bar and we have a dirty test bar when it is machined. We have had to resort either to gating the test bar separately or attached to the casting with a separate gate, or to placing the test bar in such a position that it will not get the flow of the dirt in the metal.

CHAIRMAN J. W. BOLTON: We have seen that same thing in red brass alloys, tensile test bars; one side of the bar had large crystals and on the other side the crystals were small.

R. W. PARSONS: Regarding Mr. St. John's comments, my conception is that with this particular gating at the high temperature, the gating does not work properly. In other words, as Mr. St. John suggests, the bar is not sound.

It might be, since this is poured uphill, that the metal is just hot enough to leave the bar and feed back into the gate. At the very low temperature the metal in the risers is not hot enough to permit them to function. The etched section was poured at what is known as the proper pouring temperature for that gating.

E. J. ASH:[7] With regard to the design of the gating shown as Fig. 6 of Mr. Parson's paper, I may be all wrong, but it seems to me the shrink bob is on the other end of the casting from the gate. When that bar is poured, a lot of hot metal goes through the casting into the shrink bob, and the coldest metal is then in the shrink bob.

I wonder what kind of a tensile bar would result if a shrink bob, not quite so large, were on the opposite end. Then the first metal would not remain in the test bar itself, which would give a better chance for the metal to feed into the test bar, resulting in a sounder casting.

Fig. 2, *B*, shows that the gate apparently froze off before the test bar was completely solidified, which is why shrinkage cavities are found in the test bar. Does that not affect the tensile strength? Metal is pulled from the middle—one can see the cobweb structure in the test bar; evidently there is unsound metal there.

I might point out that in case of red brass, 85-5-5-5 alloy, there is a solidification shrinkage of almost five per cent, that is, when the metal is all liquid as compared with when it is all solid. If a particular casting is not fed, it means that four per cent voids will be present. Distribute this throughout the casting in the form of intercrystalline shrinkage, and a poor structure will be the result.

W. M. BALL, JR.:[8] I agree with Mr. Ash in that I am in favor of having those shrink bobs on both ends, so that plenty of feed is obtained. The gate is going to freeze off and the feed must come from the far end of the bar or the cold end. That gate, when it is cut down, will not feed any more. In our plant we use a double end.

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[7] Research Associate, U. S. Bureau of Standards, Washington.
[8] Foundry Superintendent, Edna Brass Mfg. Co., Cincinnati.

CHAIRMAN J. W. BOLTON: We have always felt it desirable to run a little higher pouring temperature in order to get a greater feed and greater density, and to avoid incipient shrinkage throughout the material.

R. W. PARSONS: There is one thing that might be done to avoid the dead riser, that is to have the riser in connection with the sprue. If a little gate is used from the sprue to the riser and the mold is poured downhill, then the hot metal would be in the riser. This would avoid the dead riser feature. We poured the mold uphill because we felt that we got a little cleaner bar that way; that is, the dead riser also served as a dirt catcher.

Relation Between Shape of Grain and Strength of Sand

By H. Ries* and H. V. Lee,† Ithaca, N. Y.

Abstract

This paper gives the results of an investigation to determine the effect of grain shape on the strength of foundry sands. Clean sands with varying shapes were bonded with a strong ball clay and were then tested in green and dry conditions and with varying degrees of hardness of ramming. The data obtained indicate that the mixtures with rounded sand grains showed lower permeability and higher compression, in both the green and baked condition, than those with angular grains. The authors recommend further work along these lines.

1. While it is a well-known fact that molding sands may vary in their compressive strength and permeability, it is probable that this variation has usually been charged against the amount and character of bond and size of the grains.

2. It seemed possible, however, that the shape of the grains might exert some influence, and the experiments described herein may be regarded as a preliminary effort to obtaining some information on this point.

Plan of Experiments

3. The plan of work outlined consisted in selecting three pairs of sand samples free from clay bond, the grains of each pair being as nearly the same size as possible. One sand of each pair had grains that were as well rounded as it was possible to obtain, while the other one consisted of angular grains.

4. Each of these sands was mixed with 15 per cent of English ball clay, which has strong bonding power. The clay and sand were mulled in a laboratory mixer with different percentages of moisture, and then tested for green compression, green permeability and tension, as well as baked compression and baked

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† Assistant, Department of Geology, Cornell University.

Note: This paper was presented and discussed before the session on foundry sand research at the 1931 convention of the American Foundrymen's Association.

permeability. The baked specimens were heated for two hours at 150 degs. Cent.

SECTIONING

5. In addition, the baked samples also were ground to thin sections and studied under the microscope. For this purpose the specimen had to be imbedded in a hardening medium.

6. The method first tried consisted in soaking the specimen in hot kollolith, after which it was allowed to cool. However, this did not prove satisfactory as the material was not hard enough.

Table 1

No. and Size of Sand	Per cent Moisture	—Green Sand— Permeability	Compression, lbs. per sq. in.	—Baked Sand— Permeability	Compression, lbs. per sq. in.	Tension Green, oz. per sq. in.
No. 1						
Round grains	5	152	3.5	185	50	7.65
0.3-0.6 mm.	7	146	2.9	193	70	7.00
diam.	9	115	1.8	178	76	5.73
No. 4						
Angular grains	5	193	2.6	146	37	7.65
0.3-0.6 mm.	7	313	2.8	243	40	5.1
diam.	9	230	1.3	235	43	5.1
No. 5						
Round grains	5	168	9.5	119	65	9.55
0.3-0.9 mm.	7	118	3.3	119	95	12.73
diam.	9	119	2.0	160	110	7.0
No. 6						
Angular grains	5	330	2.5	300	32	7.0
0.3-0.8 mm.	7	362	1.3	312	85	5.73
diam.	9	119	1.5	230	70	6.36

7. Bakelite then was tried, and this gave more satisfactory results. The grade of bakelite used was AR-0014. This was warmed, and chips of the baked sand-clay mixture, previously warmed, were placed in it. After allowing the specimen to soak up bakelite for about an hour, it was heated at 70 degs. Cent. for 4 hours, then at 95 to 100 degs. Cent. for 6 to 8 hours. If the fragments were well hardened, they were cooled slowly and then ground to thin sections which could be studied under the microscope.

8. The data of Table 1 shows the results obtained on two pairs of sands.

9. The figures in Table 1 indicate that the mixtures with rounded sand grains showed lower permeability and higher compression, in both the green and baked condition, than those with angular grains.

10. Thin sections of the sand-clay mixture also showed that the clay seemed to be more evenly distributed around the rounded grains than around the angular ones.

EXPLANATION OF BEHAVIOR OF ROUND AND ANGULAR GRAINS

11. The difference in distribution of the clay around the two types of grains may possibly be due to several causes.

12. When the round grains are mixed in a muller type of mixer, they roll around more readily and thus become more evenly coated with clay, whereas the angular ones because of their shape will not become so regularly coated.

13. The difference in compressive strength shown by the round and angular grains may be explained by the fact that in the rounded grains we not only have a larger number of surfaces in contact, but the contact is a better one; and, since the clay is more evenly distributed, there is always a film of it between the grains.

14. In the angular ones, the contacts are very irregular, the points of contact may be very small and sufficient bonding material may not always be present.

15. The tensile strength might be affected in the same way as the compression.

16. Turning now to the permeability, we find that this behaves the reverse of the strength, being greater with angular grains than with round ones. The explanation that suggests itself here is that round grains pack together more tightly than the angular ones.

17. One interesting result developed when the effect of excessive ramming was tried. It was found that up to 4 rams with the standard rammer, the two types of grains showed a somewhat similar densification, so far as one could determine from the permeability; but from 4 up to 10 rams, the angular grains seemed to compact more than the round ones.

18. The experiments and results outlined above are to be regarded as preliminary, and not necessarily conclusive. If

further experiments are carried out, it would be very desirable to use sands that show the minimum range of grain sizes and also are very well graded as to shape. It is doubtful whether any natural sand will meet these requirements.

19. After the experiments outlined in this paper had been completed, there appeared a paper by H. C. Nipper and E. Piwowarsky,[1] in which the authors, in a somewhat lengthy paper on the properties of molding sand, discuss the relations between strength and shape of grain.

20. In this paper they remark that angular grains behave differently from rounded ones in a clay-sand mixture. They give a number of tables of compression tests, made on clay-sand mixtures containing both round and angular grains, which are interesting but not always valuable for purposes of comparison, for the reason that the different sets of mixtures were not always subjected to the same amount of ramming.

21. It is hoped that time will permit carrying out further tests along the lines described.

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[1] Formsanduntersuchungen, *Die Giesserei*, 16 Jahrgang (Neue Folge 2. Jahrgang), Heft II, p. 237, 1929.

The Interrelationship of the Pin Hole Trouble and the Low Ductility Problem

By George Batty,* Philadelphia

Abstract

In presenting this paper it is found necessary on several occasions to refer to the paper[1] by McCrae and Dowdell, and it should be definitely understood that neither the writer nor the Steel Castings Development Bureau subscribe to some of the views or opinions expressed in that paper. It should be explained that the McCrae and Dowdell test heats had been made and the tensile test results obtained before the writer became, at its inception, the director of the Steel Castings Development Bureau. The test heats had been made in varying conditions of procedure, some of which were definitely known to promote the "low ductility condition" in steel. In view of the fact that some users of steel castings might consider the widely varying results of those test heats to be representative of the normal degree of variability of physical properties in green-sand steel castings, it is thought justifiable and proper to show that a different angle of attack upon the problems has led to substantial solutions of both. The intention of the author is to adduce, in this paper, such evidence as will indicate that the interrelated problems of "pin-hole penetration" and "low ductilities" may substantially be overcome by the application of the proper technique. It is not disputed that steel treated with aluminum will, under conditions inevitably involving oxidation, be less ductile than an identical steel having no aluminum addition. It is insisted, however, that a correct focus of the major cause of decreased ductility has indicated lines of procedure that enable steel founders to produce light steel castings of appreciably higher physical properties than those indicated in the general standard specifications.

* Director, Steel Castings Development Bureau.

[1] McCrae, J. V., and Dowdell, R. L., "Deoxidation and Mold Conditions on Tensile Properties of Carbon Steel Castings;" *Proceedings*, Amer. Society for Steel Treating, 1930.

Note: This paper was presented and discussed before one of the steel sessions at the 1931 convention of the American Foundrymen's Association.

1. That which has been described as the "low ductility problem" came into being as a result of the application of a powerful deoxidizer to metal used in the production of light steel castings from acid electric steel, the deoxidizer being aluminum.

2. The foregoing brief generalization constitutes the basis of this note, but it must not be assumed that the curing of pin holes by dosing the steel with aluminum covers the whole gamut of the causes which tend to reduce the ductility of cast steel. Certain related factors will be discussed later but it seems necessary, in the first place, to keep to the broad generalization and try to trace the root causes of the pin-hole trouble and the low ductility problem.

3. "The pin-hole trouble" and "the low ductility problem" were particularly identified with green-sand practice, and it may be stated freely that these disabilities were of much rarer occurrence in dry-sand practice.

Some Considerations of Green Sand

4. Green-sand practice does not hold a place in the production scheme merely by warrant of cheapness; it is absolutely essential to the satisfactory casting of light-sectioned, intricate shapes in steel. The resistance of dry-sand molds and cores to the "solid contraction" of steel prohibits their application where light and intricate steel castings have to be produced. Good green sand does not oppose an irrelievable amount of resistance to the normal contraction of the casting and, in consequence, extravagant strains —cumulating in some cases in hot tears or cracks—are avoided.

5. Green sand has the property of producing cast steel pieces relatively unstressed by mold resistance, but it has the tendency to inject gaseous mold products through the intially solidified envelope of metal into the castings. The degree or amount of this injection of mold gases is related to the composition and constitution of the molding sand and to the temperature of the metal.

Mold Gases Come from Bonding Media

6. The mold gases or vapors cannot come from the silica grains which are the bulk and basis of molding sand; they are derived from the binding media—mineral binder, vegetable binder, used either singly or in combination, together with water.

7. The tendency of a green sand to "blow" and produce blows and pin holes is related to its moisture content, to its content of a binder which produces gases when subject to heat attack, to the actual temperature of the metal, to the proportion of heat application, as relating to local ratio of metal to mold, and to the true permeability of the sand.

8. A survey of the fundamentals has led to a system of producing a synthetic molding material for use as green sand that is largely free from the disabilities and deficiencies that were inherent in the molding sands which promoted both the pin-hole trouble and the low ductility problem.

9. Green-sand practice is an essential part in the scheme of steel castings production, and the removal of the disabilities—which at one time seemed inherent in the process—is now claimed as being substantially achieved.

10. The writer has been in this country, engaged in the steel castings industry, only since the latter part of 1927. Therefore, he has to rely to a great extent on the personal testimony of a number of foundry superintendents as to the period in which the first of the two problems or troubles became manifest.

Pin Holes with Converter Steel

11. It is stated by a number of foundry superintendents who formerly operated in shops using the converter process for the production of metal that converter metal did not give them pin-hole trouble. However, the writer must affirm that, having examined a number of castings made in the "converter era"—retained as exhibits—definite evidence was found of fine pin-hole penetration at internal angles of certain castings.

12. Still, it must be conceded, in the light of general testimony, that the pin-hole trouble became more apparent and much more of a menace to the production of light steel castings with the advent of electric furnace metal in its supersedence of the converter metal. In general, the expressed opinion indicated a belief that, for identical composition as revealed by conventional analysis, electric-furnace metal had to be made hotter than converter metal in order to give equivalent ability to run light-section castings.

13. This introduces our first variant from the previous prac-

tice, and there is not yet any unanimity of opinion as to the reason for the lower fluidity, at apparently equal temperature, of electric steel as compared with converter metal. To this point we shall revert later.

Definition of a Pin Hole

14. In discussions of the details of the manufacture of steel castings, there is a serious lack of uniformity in the terms and definitions employed, and it may be well to describe precisely what is referred to herein as a "pin hole." A pin hole is a small elongated cavity in a casting, usually visible at the surface of a casting, and generally disposed in the casting at an angle of about 90 degrees to the face of the casting at which the gas was injected.

15. Pin holes most usually occur at an internal radius; therefore, they are generally to be found in a location approximating a line perpendicular to and bisecting the chord of the arc which is the radiused corner of the mold. Pin holes are definitely "blows" from the mold—immigrant mold gases.

Remedies for Pin-Hole Trouble

16. There can be no doubt as to the original seriousness of the pin-hole trouble as manifested in many castings produced by the green-sand procees, and each manufacturer sought a solution of the problem. A very ready remedy for the pin-hole condition was found by adding to the steel an amount of aluminum which varied, in different foundries, from eight ounces to two pounds per ton of metal. In producing light steel castings, hand shanks or small bull ladles are used and the general procedure was to add aluminum to the hand shanks in an amount equivalent to the prearranged amount per ton of metal.

17. The method of adding aluminum to the metal introduces another variable which will have to be considered when we come to a discussion of the degree of embrittlement formerly resultant upon curing the pin-hole trouble.

18. As previously stated, some founders could regularly eliminate the pin-hole trouble by a small addition of aluminum, whereas other founders had to use a much larger dose of aluminum. We see that there is another variant entering into the matter, and it is submitted that this variant is, in general, the molding medium.

It is not disputed that some melters occasionally delivered metal to the pouring floor in an insufficiently deoxidized condition, but such errors were comparatively rare.

Recent Bureau Investigation

19. Some time before the formation of the Steel Castings Development Bureau, an investigation was started with a view to determining the causes of certain low ductilities noted as occurring in the production of light steel castings, as evidenced by poor elongation and reduction of area in tensile test pieces. The late J. V. McCrae was engaged on this work under the Research Associate plan at the Bureau of Standards, Washington, and when the writer became associated with the Steel Castings Development Bureau in 1928 some work had been done contributory to the results published in the proceedings of the A.S.S.T.[1]

20. About the middle of 1928 the investigation was being conducted along the lines of a study of the deoxidation of steel, and the writer took it upon himself to suggest that, while the accruing data were sure to be interesting and instructive in several respects, it could hardly be hoped that the solution of the low ductility problem lay entirely in the use of a deoxidizer other than aluminum. The writer insisted at that time—still insists—that the low ductility problem arose primarily as a result of the type of cure adopted for the pin-hole trouble.

21. The writer suggested the problem could not be accurately focused by a consideration of the matter as relating primarily to the deoxidation of the steel then used in the foundries promoting the investigation, because it was demonstrable that such steel would produce sound castings, free from pin-hole penetration, in dry-sand molds or core molds or skin-dried molds. It was insisted that the pin-hole trouble had not arisen as a result of failing to deliver to the molds satisfactorily deoxidized steel, but was caused by the re-oxidation of the metal by certain types of molds.

22. The investigation, however, was continued along the lines of its original conception for some appreciable time, and a number of deoxidizers other than aluminum were used as ladle additions and as additions to the pouring ladles or hand shanks. Other

[1] McCrae, J. V., and Dowdell, R. L., "Deoxidation and Mold conditions on Tensile Properties of Carbon Steel Castings"; PROCEEDINGS. Amer. Society for Steel Treating, 1930.

methods for the application of deoxidizers also were tried and reported upon in the paper by McCrae and Dowdell.

Mold Variations as Primary Source of Pin Holes

23. The writer's insistence upon mold variations as the primary source of pin-hole trouble—and, therefore, of the necessity, at the time and under the conditions governing the production of the test heats, for the use of supplementary deoxidizers in the pouring ladles which, in turn, resulted in decreased ductilities—was based upon a type of test mold he had adopted to serve as an indication of the suitability of sand in use as a molding medium. The test mold was devised to record the effect of both green mold and dry mold on a sample of steel.

24. A section through this test mold is shown in Fig. 1 and certainly identifies the source of the pin-hole trouble. One shoulder of the test block is produced by a core, the remainder of the mold being green sand. The quick method of checking up on these test blocks was to chip along the radius below the head of the test block. Where any unsoundness—pin-hole penetration—was found, it was invariably at the green-sand shoulder which, it is interesting to note, conforms with the typical internal angles of steel castings that were most subject to the pin-hole trouble.

25. The mechanism of the formation of pin holes is suggested in a paper[2] by the writer delivered at the 1930 meeting of the A.F.A., and it is quite logical to assume that where the heat attack of the metal on the mold is most acute, and where the facilities for the evacuation of mold gases is least propitious—the two being almost regularly consonant in practice—the liability to pin-hole penetration is at its greatest.

Deoxidizers as Cause of Embrittlement

26. The formation of pin holes inevitably represents some re-oxidation of the metal and the problem, therefore, becomes one of preventing the re-oxidation of the metal within the mold rather than one of pouring metal which contains a powerful deoxidizer in addition to the normal safe amounts of deoxidizer that have been used to make the metal normally sound.

27. It is affirmed that the problem is one of preventing the

[2] Batty, Geo., *The Most Potent Variable;* TRANSACTIONS AND BULLETIN, Amer. Foundrymen's Assn., vol. 1, no. 8, Aug., 1930, pp. 309-321.

re-oxidation of the metal, because we know that the use of a powerful deoxidizer such as aluminum results in the formation of deoxidation products which promote embrittlement. Further, it would seem that the liability to embrittlement is related to the amount of "inclusions" formed by the combination of the deoxidizer with an immigrant mold gas. If a great deal of gas is injected from the mold, a larger proportion of alumina will be formed than if only a small amount of gas is injected.

28. It is here suggested that the moisture of green-sand molds provides the majority of the immigrant gases, and if it is

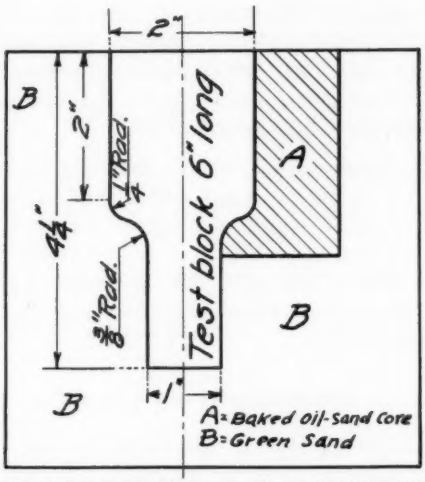

FIG. 1—SECTION OF TEST BLOCK MOLD. *A*: BAKED OIL-SAND CORE. *B*: GREEN SAND.

conceded that the dissociation products of water are injected into steel in a mold, the hydrogen may largely be absorbed by the metal and the oxygen combined with the aluminum or other powerful deoxidizer used. Further, if it is conceded that immigrant mold gases—and not gases coming out of solution from the steel—are the cause of pin holes, we must identify the trouble definitely with the mold and not with the metal.

29. This is not to say that all mild steel for castings is regularly delivered to the molds in such condition and of such constitution that highly ductile bars will be produced. There are

certain essentials of steel-making procedure to be regularly followed if satisfactorily ductile material is to be produced.

Mechanism of Pin-Hole Penetration

30. It would seem politic at this point to indicate what the writer believes to be the mechanism of pin-hole formation and at the same time to explain why some castings do not show pin holes at internal angles until after they have been annealed and the annealing scale removed. This explanation was made briefly and sketchily during the writer's reply to a discussion of his paper at the A.F.A. convention in Cleveland, 1930.

31. It is suggested that the heat attack of metal on mold is most acute at the places where an internal corner of the casting is produced by the mold. At such a location an unsuitable mold will cause a blow of such magnitude that it has often been termed "shrink" by practical foundrymen.

32. Along internal angles of a casting the heat of the metal attacks two faces of the mold and, consequently, there is a degree of mold-gas generation which, although less than that occurring at an internal corner of a casting, is greater than that occurring at the plain surfaces of the mold. The diagrams of Fig. 2 indicate what is believed to occur when metal fills a green-sand mold of unsuitable composition.

Illustrations of Mechanism

33. It must be understood that the writer believes blows and pin holes—pin holes being definitely blows from the mold—to be entirely due to a constitution of mold incompetent to evacuate in the proper direction all the additional volume of gas generated by the heat attack of the metal upon mold constituents.

34. Fig. 2-*A* postulates the condition at an internal angle of mold shortly after it has been covered by metal. The direction of properly evacuating gases is indicated by the arrows pointing from the mold-metal interface. The broken line within the mold area indicates the deposition of a film of moisture which is produced by the primary volatilization of the moisture near the mold face and its almost immediate condensation by contact with cooler sand. The continuation of heat transference from metal to mold promotes again the production of steam at the internal face of this

condensate film, and it is readily conceivable that such a reversal occurs most acutely where the heat attack is greatest, namely, at the internal angle of the mold.

35. It is believed that, as the corner of the mold is less competent to evacuate the generated or enlarged gases and vapors, the pressure engendered at the angle of the mold will be sufficient to allow the vapors to expand the initially solidified envelope of metal in contact with the angle of the mold—the solidified envelope being thinner in this location than at the plain faces—and release it from contact with its cooling medium, the mold. The first release of the solidified envelope is indicated in Fig. 2-*B*.

36. As the solidified envelope is stretched by the pressure of the gas or vapors, it is believed that it ruptures and allows the

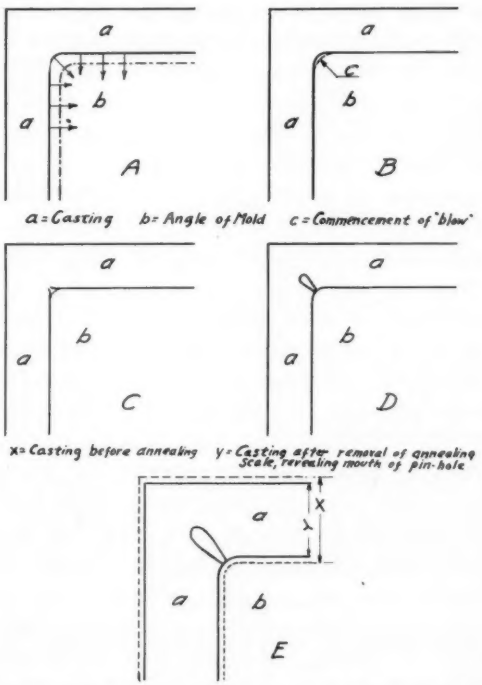

FIG. 2—SECTION OF MOLD AND CASTING, SHOWING VARIOUS CONDITIONS PREVAILING.

vapors to enter the body of the casting which is still in a highly plastic or even fluid condition. This injection is indicated in Fig. 2-*C*.

37. If the injection of gases or vapors takes place while the interior metal is still appreciably fluid, it is conceivable that when the gas has entered the metal the ruptured envelope may be folded back into close contact with the mold—as illustrated in Fig. 2-*D*—and leave no visible evidence of the pin hole. Such castings, therefore, would show no sign of pin hole penetration at internal angles when examined after sand blasting, but cases have come under the writer's notice where castings that appeared perfectly sound before annealing have shown a number of pin holes after the annealing scale had been removed.

38. Fig. 2-*E* indicates an extravagant amount of annealing scale if the figure were to be considered as indicative of the proportion of metal scaled in annealing, but the drawing out of proportion is made to indicate clearly the removal of so much surface metal, by scaling, as will expose the end of the pin hole. It is quite easy to establish the fact that the healed lips of the ruptures may be so thin that the removal of only a few thousandths of metal reveals the mouth of a pin hole.

Pin Holes Show After Removal of Scale

39. This condition—where castings have appeared sound before annealing and pin holed after the removal of the annealing scale—is indicative of what might be described as early blow from the mold. An examination of such castings frequently will reveal cavities within the metal near an internal angle of the mold that have no connection with the interior surface of the casting but are totally isolated.

40. The most general pin-hole condition that had to be cured was caused by what might be described as a later blow from the mold which produced pin holes of such form that they could be seen at the internal angles of the castings after the sandblasting operation.

Most Blow Holes Probably Caused by Moisture Content

41. It is believed that most blows and pin holes in green-sand castings were caused by the moisture content of the sand,

because it is quite easy to establish the fact that skin drying will permit of the production of perfectly sound castings from molds which would have produced hopelessly pin-holed castings if used in the true green state.

42. Skin drying does not result entirely in the evolution, as water vapor, of the moisture at the surface of the mold. Some of the moisture is driven back from the face of the mold into the interior as water vapor and is condensed by the cooler sand with which it contacts. In a properly skin-dried mold this condensate film is so remote from the mold-metal interface that the solidified envelope of metal is so thick when the gas pressure becomes acute that it can resist penetration.

43. The constitution of the molding medium for green-sand castings, therefore, becomes our focal point. It necessarily follows that, by preventing the injection of mold gases, we should prevent the formation of pin holes and thereby should be absolved of the necessity of using a supplementary powerful deoxidizer as a late addition to the pouring ladles.

44. We have not been able to produce a green sand which will not inject some gas into the castings, but we have so modified the procedure of producing green sand that the injection of mold gases is almost insignificant. As a result, we have so reduced the amount or proportion of "alumina embrittlement" that we consider the low ductility problem substantially solved.

Investigation on Deoxidizer Continuing

45. This is not to say that we consider the matter closed. We are proceeding with investigations with a view to finding a means of applying a deoxidizer that will not have the same effect as aluminum in promoting decreased ductility.

46. Although we consider that the low ductility problem is substantially solved—in that we are regularly able to meet ductility specifications with an appreciable margin over specification limits of elongation per cent and reduction of area per cent, together with considerably greater strengths than those demanded by the specifications—we are seeking means to overcome the degree of embrittlement which is, in present practice, a concomitant of "killing" the seemingly inevitable amount of immigrant mold gases.

Aluminum as Supplementary Deoxidizer

47. When aluminum is used as the supplementary deoxidizer —and aluminum generally is used in this application—the product of the reaction with an immigrant gas is alumina. We have no evidence that 0.05 per cent aluminum in steel exercises any serious embrittling effect, but we have some considerable evidence that a small amount of alumina promotes a noticeable degree of embrittlement. If, therefore, the injection of mold gases is limited, the formation of alumina will be limited and the resultant product proportionately influenced in respect of ductility as compared with an identical steel cast without aluminum addition.

48. Comstock has suggested[3] that "in the aluminum treated steel" . . . (presumably a steel contaminated with alumina) . . . "the sulphides are practically always very fine and arranged more or less distinctly in streaks forming a sort of fragmentary network. Steels cast without aluminum normally have their sulphide inclusions coarser, globular and more scattered, like the silicate globules. In the tensile test the streaks of fine sulphides have a tendency to cause cracks to open up in the specimen after the yield point is passed, and these cracks grow under the increasing load so that the specimen breaks with less elongation and reduction of area than if the cracks had not opened."....."We have found that low ductility could be correlated with the streaky sulphide arrangement more closely than merely with the presence of segregated alumina inclusions, although, as stated, both these characteristics often occurred together."

Low Versus High Sulphur Content

49. In relation to the foregoing quotations of Comstock, it is interesting to note that the alumina embrittlement (so-called) of basic elecric steels of low sulphur content is less marked than is the case with the acid electric steels of higher sulphur content. This aspect of the case has not yet been investigated by the writer but must certainly indicate a line of investigation potentially instructive and profitable.

50. It does not seem to be generally known that some aluminum is added to a charge when the ordinary commercial brand of

[3] Discussion, "Production of Electric Steel for Castings" by Geo. Batty; *Proceedings*, Amer. Soc. for Steel Treating, 1929.

ferrosilicon is used as a deoxidizer. Undoubtedly the aluminum so added—contained in the ferroalloy—has considerable opportunity for levitation, as alumina, both in the furnace and in the ladle; hence, we are not likely to find any aluminum present in a sample of steel taken from the ladle as it is delivered to the pouring floor.

Converter Versus Electric Furnace Metal

51. In the consideration of our two related problems, we must revert to the general testimony of men who have been accustomed to make light steel castings from converter metal without additions of aluminum either to the large ladle or to the pouring ladles. These witnesses generally insist that converter metal could be used cooler than can electric furnace metal, and if such is the case, we have, in the actual temperature employed in pouring electric steel, an added liability to the production of pin holes.

Investigation of Molding Media

52. Largely, the remedy for the pin-hole trouble lies in producing a suitable molding medium for green-sand practice, and some considerable investigation as to the best molding media has been made by the foundries who are members of the Steel Castings Development Bureau. It is found that, by using a pneumatic exhausting system in combination with vibratory screens, sand may be reclaimed and put into excellent condition for re-use.

53. The bonding media employed are bentonite and a cereal binder. Regularity of grain size is an essential, and a supply of sand is used as the basis material which is regularly subangular or rounded in grain shape. Sand control of the reclaimed material is directed to maintaining a proportion of not less than 4 per cent and not more than 7 per cent of fines—material passing the 100-mesh screen—such fines exercising a function as bond diluent.

54. As the reclaiming system embodies a pneumatic extractor, there is a fair assurance that finely divided ferrous oxide is almost completely withdrawn from the sand and, consequently, there is no accumulation of this dangerous component in the reclaimed sand through its many cycles of use.

55. New sand is almost entirely introduced as oil-sand cores

which, after exercising their primary function, become the "new" material to repair the wastage resultant upon sand adhering to castings and such part of the sand as is so finely fragmented in service as to be eliminated by the screen or the air exhaust. The majority of the grains of reclaimed sand are finely coated with strongly adherent unperished bond, and only a small amount of new bonding material is added to the reclaimed sand to produce the regular molding sand.

Suitability of Green Sand for Molding

56. The suitability of the green sand for molding is readily assessed by pouring test blocks into molds of the type illustrated in Fig. 1. The use of such an actual service test is strongly to be commended as an amplification of the more regular sand-control methods practiced in the routine determination of permeability, moisture content and strength.

57. A simple chipping or grinding of the two internal angles produced beneath the head of the test block serves as a very reliable indication of the suitability of the molding sand. At the same time, the test block will identify any heat of metal that is improperly made, in respect of adequate deoxidation. Pin holes from the green-sand shoulder of the mold definitely indicate a dangerous molding medium, while subcutaneous blow holes at both shoulders of the mold would indicate unsound, wild, or "blowy" metal.

Investigations Since June, 1928

58. In considering the results which had already accrued in June, 1928, in the investigation reported on by McCrae and Dowdell in 1930, the writer related the variable ductilities definitely to variables in mold conditions and, believing the real direction of attack on the problem to be "mold condition," proceeded to regularize the practice of producing green molding sand in the foundries of the Steel Castings Development Bureau.

59. It is conceded that the McCrae-Dowdell paper deals with steels of which many were of unsatisfactory properties as regards ductility, but it is thought by the writer that the publication of such data as the records on the 132 heats of steel might create the impression that green sand is an unsuitable medium for the production of high-grade steel castings. A series of heats made in

Table 1

CARBON RANGE, 0.30 TO 0.38 PER CENT.

Heat No.	C	Mn	Si	S	P	Yield point, lbs. per sq. in.	Tensile strength, lbs. per sq. in.	Elongation, %	Reduction of area, %	Bend, Degs.		Heat Treatment
7860	.38	.70	.36	.034	.031	46,300	82,000	27.00	37.50	180	unbroken	1650° F. 4. hrs. air cool
						48,250	80,500	26.00	43.60			1300° F. 5 hrs. fce. cool
7992	.32	.63	.32	.032	.037	41,650	70,000	30.00	50.84	180	unbroken	1650° F. 4 hrs. air cool
						44,150	70,400	30.00	50.05			1250° F. 4 hrs. fce. cool
7997	.30	.61	.34	.034	.035	40,250	70,750	30.00	50.84	180	unbroken	Same as for Heat No. 7992
						38,850	70,500	30.00	50.59			
8002	.30	.55	.48	.037	.041	35,650	66,850	32.50	50.30	180	unbroken	Same as for Heat No. 7992
						35,900	66,850	30.00	52.30			
8042	.30	.72	.34	.038	.037	48,300	75,400	25.50	39.70	180	unbroken	Same as for Heat No. 7992
						47,900	75,750	28.50	47.45			
8249	.30	.75	.31	.035	.036	44,150	72,600	30.00	50.29	180	unbroken	Same as for Heat No. 7992
						43,750	72,500	26.00	36.00			
9363	.30	.68	.32	.031	.025	38,600	73,250	27.50	49.45	180	showing cracks	Same as for Heat No. 7992
9403	.30	.70	.35	.032	.029	45,250	75,950	27.50	49.75	180	unbroken	Same as for Heat No. 7992
9409	.32	.73	.31	.035	.031	44,100	74,000	27.50	46.60	180	unbroken	Same as for Heat No. 7992

Table 2

CARBON RANGE, 0.26 TO 0.29 PER CENT.

Heat No.	C	Mn	Si	S	P	Yield point, lbs. per sq. in.	Tensile strength, lbs. per sq. in.	Elongation, %	Reduction of area, %	Bend, Degs.		Heat Treatment
7969	.27	.62	.28	.029	.038	40,000	70,000	33.00	49.70	180	unbroken	1650° F. 4 hrs. air cool
						39,850	70,000	29.00	47.70			1250° F. 4 hrs. fce. cool
7975	.28	.59	.31	.044	.040	40,900	70,750	28.50	43.30	180	unbroken	Same as for Heat No. 7969
						39,600	70,600	29.00	46.80			
7984	.27	.60	.34	.035	.046	41,700	68,750	30.00	48.60	180	unbroken	Same as for Heat No. 7969
						41,100	68,900	30.00	49.40			
7999	.29	.68	.30	.044	.036	43,650	72,100	27.50	46.60	180	unbroken	Same as for Heat No. 7969
						43,800	72,400	29.50	48.20			
8021	.26	.65	.34	.034	.042	42,750	69,250	28.50	44.50	180	unbroken	Same as for Heat No. 7969
						43,500	69,400	28.50	46.30			
8027	.28	.61	.31	.049	.035	37,300	70,000	28.50	46.30	180	unbroken	Same as for Heat No. 7969
						38,000	70,250	27.50	43.90			
8039	.28	.75	.33	.042	.036	46,300	74,500	25.50	38.61	180	showing flaws	Same as for Heat No. 7969
						46,850	74,300	25.50	41.25			
8047	.27	.53	.35	.037	.042	38,500	67,000	30.00	49.70	180	unbroken	Same as for Heat No. 7969
						36,400	67,350	29.50	49.70			
8056	.27	.76	.29	.046	.037	44,600	69,500	29.50	46.60	180	unbroken	Same as for Heat No. 7969
						44,400	69,750	30.00	47.40			
8066	.28	.79	.31	.030	.032	43,250	75,400	29.00	43.90	180	unbroken	Same as for Heat No. 7969
						46,000	75,850	28.00	46.00			
8356	.29	.64	.31	.037	.025	40,400	67,850	30.00	44.85	180	unbroken	Same as for Heat No. 7969
8541	.26	.61	.31	.038	.027	36,450	65,200	35.00	55.19	180	unbroken	Same as for Heat No. 7969
9396	.27	.72	.31	.030	.023	43,450	71,850	27.00	45.15	180	unbroken	Same as for Heat No. 7969
9399	.28	.66	.31	.028	.030	43,900	70,500	27.50	47.20	180	slight crack	Same as for Heat No. 7969
9407	.27	.65	.31	.034	.030	43,200	70,500	29.00	52.49	180	unbroken	Same as for Heat No. 7969

Table 3

CARBON RANGE, 0.22 TO 0.25 PER CENT.

Heat No.	C	Mn	Si	S	P	Yield point, lbs. per sq. in.	Tensile strength, lbs. per sq. in.	Elongation, %	Reduction of area, %	Bend, Degs.		Heat Treatment
7957	.25	.54	.32	.047	.043	38,500	67,500	32.00	52.50	180	unbroken	1650° F. 4 hrs. air cool
						38,750	67,100	32.00	54.40			1250° F. 4 hrs. fce. cool
7963	.24	.60	.29	.039	.044	41,750	66,800	31.00	52.50	180	unbroken	Same as for Heat No. 7957
						38,150	67,200	31.50	49.70			
7979	.24	.58	.29	.049	.041	37,800	67,100	32.50	52.20	180	unbroken	Same as for Heat No. 7957
						37,100	66,750	32.00	51.90			
8017	.23	.59	.28	.040	.037	42,100	68,750	27.50	46.00	180	unbroken	Same as for Heat No. 7957
						41,150	68,400	31.00	49.10			
8025	.22	.70	.29	.041	.039	43,500	68,250	30.00	55.19	180	unbroken	Same as for Heat No. 7957
						43,900	67,850	30.00	50.84			
8031	.22	.55	.36	.048	.038	41,600	68,000	28.00	44.50	180	unbroken	Same as for Heat No. 7957
						43,350	68,000	29.00	45.40			
8035	.24	.76	.35	.038	.040	43,250	73,500	28.00	44.25	180	unbroken	Same as for Heat No. 7957
						45,750	73,500	27.50	45.15			

1929—reported upon in the same paper—show that very different results were obtainable as a result purely of altered mold conditions.

60. Table XXA in the McCrae-Dowdell paper is rather a striking refutation of the indications adduced by the preliminary survey on the 132 heats.

61. In their summary the authors state: "The tendency toward low ductility is related to the carbon content of the steel. This preliminary survey indicated, in general, that if the carbon content is maintained between 0.10 and 0.17 per cent, the manganese between 0.60 and 0.70 and the silicon content between 0.30 and 0.40, the addition of about one pound of aluminum per ton of steel to the working ladle shortly before pouring will not lower the ductility of the normalized casting below the usual specified limits."

Physical Properties Recorded

62. The results of physical properties quoted in their table XXA may be amplified by the data of test results shown in Tables 1, 2 and 3.

63. A large number of castings had to be made to conform with the following specifications:

Yield point 35,000 lbs. per square inch
Tensile strength, 65,000 lbs. per square inch
Elongation, 20 per cent in 2 inches
Reduction of area, 30 per cent
Bend, 120 degrees
Test pieces, tensile standard 0.505 in. diameter bar
Bend, standard, 1/2 × 1 × 6 inches with corners slightly rounded as per A.S.T.M. specifications.
Test coupons all to be attached to castings.

64. The test coupons were attached to castings in the manner as shown in Fig. 3.

Test Procedure Followed

65. The production of this large number of castings was spread over a considerable period, and one test coupon was taken by the inspectors as being representative of all that particular type of casting in the heat. It frequently happened that castings

of this particular type were made from metal which had to meet much more rigorous specifications, in respect of strength, than is indicated in the specifications covering these particular sockets.

66. The castings and test coupons were all poured in green-sand molds and, for purposes of comparison, the test heats are divided into three separate carbon ranges in order to present some demonstration of the wide range of composition that can be made to conform to fairly high ductility specifications.

67. Tables 1, 2, and 3, respectively, cover carbon ranges of 0.38 to 0.30 per cent, 0.29 to 0.26, and 0.25 to 0.22 per cent. The physical test results in these tables show that with proper green-sand practice it is possible to produce physical properties which

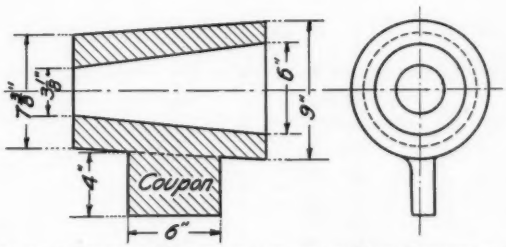

FIG. 3—DIAGRAM SHOWING MANNER OF ATTACHING TEST COUPONS TO CASTINGS.

are in all essentials considerably superior to the minima expressed in Navy B specification. Navy B specification was the index to which was related the McCrae-Dowdell investigation on the 132 heats.

Reclaimed Sand Used

68. The molding material used in the production of these heats was reclaimed sand from which dust and fines had been extracted to the extent of leaving between 4 and 7 per cent of fine material in the reclaimed sand, such fine material being, in the main, fine grains of sand that would pass the 100-mesh sieve. A typical grain-size analysis of this dry reclaimed sand, as it is delivered to the mill for rebonding, is given in Table 4.

69. It should be understood that the material listed in Table 4 is not all clean silica sand—it is silica sand grains coated with a fine remanent film of bonding material added in its previous

cycle of use. This bond film increases the individual grain size but is so strongly adherent in the dry condition that it does not readily rub off in the sieving operation. To such basis material is added 1 per cent of bentonite and 0.5 per cent of cereal binder which, together with between 3.5 and 4.2 per cent moisture, produces a molding medium having a permeability of about 140 and a compression strength of about 7.4 lbs. per sq. in.

70. The green sand records covering the period in which the heats were produced, as reported upon in Tables 1, 2 and 3, show a variation in moisture content of from 3.4 to 4.1 per cent—samples being taken from the molders' supply bins—permeabilities ranging from 120 to 150, and compression strengths from 6.5 to 7.8 lbs. per sq. in. The aluminum addition to the heats of steel

Table 4

TYPICAL GRAIN-SIZE ANALYSIS OF DRY RECLAIMED SAND

Sieve No.	Amount %
On 20	0.88
On 30	4.33
On 40	23.98
On 60	50.28
On 80	12.50
On 100	3.97
Pan	3.48

was the standard amount for the foundry—12 ounces per ton of metal—and this aluminum was added to the metal by wiring it strongly on a rod and plunging to the base of the metal in the ladle.

Bend Tests

71. Relative to the bend tests in Tables 1, 2 and 3, it should be stated that the samples were bent over a radius of 5/8 inch to 120 degrees, and were then gripped between the jaws of the machine and pulled in as far as possible.

Tests on Steels with Carbon Above 0.22 Per Cent

72. A further series of tests on steels containing not less than 0.22 per cent carbon, and with higher manganese contents than the steels listed in Tables 1, 2 and 3, is shown in Table 5.

Table 5

CARBON NOT LESS THAN 0.22 PER CENT—HIGHER MANGANESE.

C	Mn	Si	S	P	Yield point, lbs. per sq. in.	Tensile strength, lbs. per sq. in.	Elongation, %	Reduction of area, %	Bend, Degs.		——Heat Treatment——
.22	.81	.40	.035	.025	43,800	83,500	31.00	55.60	120	unbroken	1650° F. 3 hrs. normalized
.23	.90	.39	.037	.028	44,500	79,450	33.00	53.7	120	unbroken	Same
.25	.88	.38	.037	.029	47,050	81,300	33.00	53.0	120	unbroken	Same
.22	.84	.39	.038	.028	48,750	77,700	34.00	47.5	120	unbroken	Same
.25	.85	.40	.037	.025	47,100	77,850	31.00	51.0	120	unbroken	Same
.25	.88	.39	.036	.026	48,400	76,850	32.00	53.0	120	unbroken	Same
.25	.79	.38	.037	.026	43,500	76,750	31.00	57.0	120	unbroken	Same
.24	.76	.37	.039	.028	49,600	80,800	33.00	49.0	120	umbroken	Same
.25	.81	.40	.036	.027	43,500	76,300	35.00	54.0	120	unbroken	Same
.31	.96	.39	.036	.029	42,150	82,550	26.00	35.0	120	unbroken	1650° F. 3 hrs, air quench; drawn 2 hrs. 1250° F. air quench.
.27	.91	.38	.036	.028	43,200	76,800	32.00	49.8	120	unbroken	Same
.30	.97	.36	.034	.027	43,800	82,250	32.00	47.0	120	unbroken	Same
.22	.95	.38	.038	.031	47,200	81,050	31.00	56.4	120	unbroken	Same
.25	.91	.38	.037	.029	46,650	81,500	30.0	51.0	120	unbroken	Same
.30	1.13	.38	.036	.027	56,850	86,100	27.5	60.0	120	unbroken	Same

73. The embrittling effect of aluminum may be found more marked when aluminum additions are made to hand shanks or other small pouring ladles. The tests reported in Table 5 relate to samples cut from test blocks poured from hand shanks which received small additions of aluminum to an amount approximating eight ounces aluminum per ton of steel.

74. Such test blocks were produced in green-sand molds to be representative of the general conditions pertaining in the production of green-sand castings, and it is submitted that these tables of tests, which may regularly now be duplicated, prove that the so-called low ductility problem is substantially solved, consonant with the elimination of the pin-hole trouble, by producing green-sand molds of proper composition and constitution.

Aluminum-Treated Steels and Low Ductility

75. In an earlier part of this note it was suggested that mold gases injected into aluminum-treated steels created almost the whole of the low ductility problem. It is conceded that causes other than injected mold gases may produce the embrittled condition in steel for castings, and brief mention of two of these causes may be made here as separate from the interrelationship of the pin-hole trouble and the low ductility problem.

76. Alumina undoubtedly promotes an embrittled condition in steel for castings, but such alumina may be produced as a result of careless practice in the foundry. There is, unfortunately, a tendency in many quarters to drift slowly away from the rigors of good practice, and it becomes the duty of all those exercising supervisory authority in steel foundries to insist upon the observance of seemingly small details of procedure.

77. The actual method of adding aluminum to a hand shank or small pouring ladle inevitably involves some small production of alumina and consequently some proportionate effect upon the ductility of the metal. It is considered safe practice to insure the presence of a small amount of aluminum in steel for green-sand castings in order that there may be present a safeguard against pin-hole unsoundness in the case of a small but not serious injection of gases from the mold. This inevitably involves some slight recession from the higher standard of ductility obtainable from steel of identical composition other than the aluminum addition.

Sand Control Must Be Maintained

78. It is submitted that, with proper control of sand composition and mold constitution, the degree of depreciation of ductility is so reduced as to make possible the meeting of the standard specifications with a fairly generous margin in respect of both ductility and strength.

79. The sand is the chief problem, and it is appalling to contemplate any negation of the care exercised in sand preparation as a result of careless practice in adding aluminum to the pouring ladles that are to produce the small castings. In the course of the writer's experience a number of defects have been noted and almost entirely eliminated in practice.

Precautions Connected With Ladles

80. A hand shank returning to the large ladle for a further supply of metal often contains a small amount of steel which is still liquid, and if aluminum is added to this small amount of steel in the hand shank and then an interval of even a few seconds supervenes before the hand shank receives the further supply of metal from the large ladle, almost the whole of the added aluminum will be oxidized and will contaminate the shank load of steel with alumina.

81. Aluminum should be added to hand shanks as the metal is flowing from the large ladle into the shank, and care should be taken to throw the aluminum into the stream of metal so that it may be carried down as far as possible below the surface.

82. Shanks or pouring ladles with dirty lips almost inevitably promote the formation of alumina in the metal either before or as it enters the mold. A shank or pouring ladle is considered dirty when it has a film of solidified metal upon any part of its interior surface.

83. This solidified metal oxidizes very readily and, when the shank receives another load of metal and its usual amount of aluminum, the oxide of iron on the solidified film inevitably is reduced by the aluminum with the formation of alumina. Alumina, no matter how produced, inevitably involves or promotes some embrittlement of the steel.

84. The addition of small pieces of aluminum to the stream

of metal as it enters the mold is deprecated as being likely to produce uneven aluminum distribution through the casting. If pellets or small pieces of aluminum are thrown into the stream of metal as it enters the mold, hard spots may be produced in the casting as a consequence.

Inclusion and Embrittlement

85. The embrittling effects of included, finely divided silica or silicates is a matter that will have to be discussed at some other time. Such silica or silicate inclusions may be the result of inferior melting practice or may be the result of either inferior mold materials or inadequate molding method.

86. So far as silica or silicate inclusions in the metal are concerned, it is well to remember that aluminum appears to have the ability rapidly to break up such compounds with the resultant formation of alumina. A dirty steel—that is, a steel appreciably contaminated with finely divided silica or silicates—will become contaminated with alumina by the simple addition of aluminum to the hand shanks or pouring ladles.

87. The production of "clean" steel, therefore, is a matter that impinges directly upon the low ductility problem; but, notwithstanding the foregoing potential causes of embrittlement, it is asserted that the real low ductility problem was primarily the result of overcoming the pin-hole trouble by making aluminum additions to the steel in the pouring ladles. Having established as a fact an ability to overcome to a very large extent the tendency of green-sand molds to inject oxidizing gases into the casting, it is believed that the major cause of decreased ductility is overcome.

88. Reverting now to the difference of fluidity—or "runability"—claimed to exist as between converter steel and acid electric steel, it is interesting to note that some observers claim that converter steel is highly fluid because of the thermal product of the continuing reaction of FeO with Mn and Si (with the inevitable production of SiO_2 and MnO), while other observers[4] have suggested that the comparatively low fluidity of electric steel may be related to "an excess of metallic silicon at the surface of the liquid metal."

[4] McCrae, J. V., Dowdell, R. L., and Jordan, L., "A Study of the So-Called 'Over-Reduced' Condition in Molten Steel:" Research Paper No. 250, *Bureau of Standards Journal of Research*, vol. 5, Nov., 1930.

SUMMARY

89. Pin holes are produced by the thermal attack of metal upon molding material which is not competent properly to evacuate its gases and vapors. The higher the temperature of metal, the greater will be the liability to the injection of mold gases into the metal.

90. Pin holes are formed by gases—largely the dissociation products of water—injected from the mold into the solidifying metal. They are not produced by gases released from solution in the steel.

91. Aluminum is used to combine with injected oxygen—hydrogen being, presumably, readily absorbed by the steel—and so prevent the formation or persistence of pin holes.

92. In "killing" the injected oxygen, alumina is formed which causes or promotes an embrittling of the metal. This embrittlement seems to bear some definite relation to the amount of alumina formed. The embrittlement, therefore, may be directly related to the amount of injected oxygen when sufficient aluminum is present to combine with the whole of such oxygen.

93. Alumina may also be formed by aluminum reducing the oxides of silicon, manganese and iron. Silica and silicates of iron and manganese may exist in dangerous amounts in steel as the metal is delivered to the pouring floor. Such dirty steel does not have highly satisfactory ductility properties, but if the silica and silicates are reduced by aluminum in the working ladles, the alumina contamination promotes a more acute embrittlement than that consonant with the silica and silicate inclusions. Such, however, is considered the minor source of alumina embrittlement, the major source of this condition being believed to be immigrant mold gases.

94. As embrittlement is promoted by alumina—as distinct from aluminum—and as alumina in steel castings is most generally formed by the injection of mold gases into aluminum-treated steel, the cure of both the pin-hole trouble and the solution of the low ductility problem are to be achieved by the provision of a green-sand molding medium of proper constitution and composition. Insofar as the injection of oxidizing mold gases into clean metal is prevented or limited, the pin-holing of castings and the depreciation of ductility of the steel may be eliminated.

DISCUSSION

WRITTEN DISCUSSION

H. S. RAWDON:[1] At the time the work on "The Effect of Deoxidation and Mold Conditions on the Tensile Properties of Carbon Steel Castings,"* reported on by J. V. McCrae and R. L. Dowdell, was undertaken, the problem of the "low ductility" of cast steel was rather an obscure one. This work was carried out by the Steel Castings Development Bureau (previous to formation of this association, by several foundries who later became members of the association), through their research associate, J. V. McCrae. The laboratory work was done at the Bureau of Standards, but the preparation of the test heats was carried out under plant conditions in the foundries cooperating in the work.

The fact that this was a problem deserving serious study was strikingly demonstrated by the results of the first phase of the work, consisting of a study of 132 heats of steel, 100 being consecutive heats made in one plant, and 32 consecutive heats in another plant. All the results of this phase of the work could not be included in the published report.

A wealth of experimental data was accumulated in the course of the work, and in the preparation of the published report only the more important of these data could be included. Contrary to the statement in Mr. Batty's prefatory abstract, the report by McCrae and Dowdell is singularly free from "views and opinions" to which exception may be taken. A painstaking effort was made to include in the report only such conclusions as could be supported by the experimental data.

The basis on which the investigation was planned was, of course, largely an assumption, that is, that pouring of molten metal into a green-sand mold gives rise to conditions which are largely responsible for the undesirable properties often shown subsequently by the metal. This also is true, however, of the present paper under discussion.

It may not be amiss to emphasize the fact that the phenomenon of "pin-holing" discussed is not synonomous with porosity in general, such as readily occurs in "wild" steel. The statement of Mr. Batty that pin-holing may occur in a well-made deoxidized steel under improper mold conditions is believed to be correct.

Obviously, there are two lines of possible solution of the problem that will occur to the metallurgist. The first is to treat the steel just before it is poured into the molds, as is done in numerous other instances for degasification of metals with the hope that the ductility of the sound metal secured by the treatment will not be greatly affected by the presence of the products resulting from the treatment.

The other solution is to attempt to improve the mold into which the metal is poured so that conditions will not arise to affect the metal so adversely. It should be borne in mind, however, that no improvement of the mold, no matter how satisfactory, can dispense entirely with the de-

[1] Chief, Division of Metallurgy, Bureau of Standards, Washington.

* *Transactions*, Amer. Society for Steel Treating, vol. 18, p. 159, 1930.

oxidation treatment of the steel required in the course of the regular steel-making process.

Both of these methods received consideration in the work reported upon by McCrae and Dowdell, although the deoxidation treatment was the one which received most attention. Only a relatively few results on the second method of improvement were available at the time the first report was published.

The present paper by Mr. Batty serves mainly to amplify the discussion of the second method of solving the problem of "low ductility." It is to be regretted, however, that more detailed information on the means adopted for the improvement of the mold conditions has not been given in addition to the tensile properties of the steel cast in such molds.

The success claimed for this method of mold improvement serves admirably to emphasize the great importance of the research on the properties of foundry sands and the methods for testing them which has been so actively supported by the American Foundrymen's Association for a number of years. Obviously, without the backing of this and similar research on sands, such improvements would be handicapped greatly, if at all practicable.

A point of minor importance in Mr. Batty's paper, and one which probably will not be accepted by metallurgists in general, is the explanation given of the mechanism of the formation of the pin holes. The accumulation of gas adjacent to the metal under sufficient pressure to rupture the surface layer of *solidified* metal, followed by the "heating" of the numerous surface perforations thus formed, cannot be readily visualized. Nor does the explanation seem to fit the facts.

If the mold gases enter the molten metal in bubbles as large as and probably larger than the resultant pin holes, it would seem exceedingly doubtful that the simple deoxidation treatment of the metal (such as experience has shown is sufficient) could remove these gas bubbles after they once have been formed. It also is reasonable to expect that it should be possible to find some evidence in the microstructure supporting this explanation of their mechanical formation. To the writer's knowledge, such evidence never has been found.

The production of reliable and dependable metallic materials is the ultimate aim of the metallurgist. Not all the methods studied can be expected to result directly in marked improvements. However, if an investigation serves to point a way by which the desired end can be attained more readily, it will have justified itself and served a very useful purpose. It is the writer's feeling that this can well be said of the work on the low ductility of cast steel.

R. L. DOWDELL:[2] Mr Batty infers very strongly that the Steel Castings Development Bureau has no trouble in obtaining the high properties given in Table 1, 2, 3 and 5 of his paper, but I think he must admit that there is considerable difficulty in producing regularly castings which will meet the so-called Navy-B specifications even with elaborate sand control. It also is inferred in Mr. Batty's paper that the original investigators of

[2] Professor of Metallography, University of Minnesota, Minneapolis.

the problems submitted by the Steel Castings Development Bureau were unaware of the fact that mold materials had to do with the question of "pin holes."

In speaking for these early investigators at the Bureau of Standards, I must admit that these men were quite familiar with the problem and were working along the lines of various deoxidizers with the hope that one could be found which would eliminate the necessity of controlling sand conditions to a high degree. The following quotation from our paper explains the situation more accurately, I think, than is indicated by Mr. Batty's comments:

> "From the beginning of this investigation it was believed that variables in green sand practice, especially moisture, were largely responsible for difficulties encountered from pin holes in most steel products. It was thought, however, that sand control would be harder to maintain to a high degree than would some suitable deoxidizer which might insure soundness without ductility."

When the major part of the research at the Bureau was ready for publication, the cooperating organization claimed they had the problem under definite control, and an opportunity was given them to show this control. They produced six heats at each of three foundries and after making the customary tensile tests from representative green-sand bars it was found that the results from one plant showed a complete failure. The results from the other plants are given in Table XXA, page 39, of our paper. Even the data given from the two remaining plants, Table XXA, are not in complete agreement with the data given by Mr. Batty.

Paragraph 61 of Mr. Batty's paper only partially indicates, in the quotation made, the summaries in our paper presented before the A. S. S. T. In paragraph 88 of Mr. Batty's paper, he quotes us as having mentioned "an excess of metallic silicon at the surface of the liquid metal." This is but a portion of a direct quotation, important matter having been omitted from the middle of the statement.*

In conclusion, it must be admitted that the beginning of the abstract of Mr. Batty's paper is not very complimentary to the work done primarily by the late J. V. McCrae, who contributed considerable valuable research to the field of steel castings.

ORAL DISCUSSION

J. H. HALL:[2] There are many features of this paper—and let me say that I consider it an admirable piece of work, admirably presented—with which I am in entire agreement. With all due respect to Mr.

* McCrae, J. V., Dowdell, R. L., and Jordan, Louis, "A Study of the So-Called 'Over-Reduced' Condition of Molten Steel"; *Bureau of Standards Journal of Research*, vol. 5, p. 1123, 1930.

[2] Technical Assistant to President, Taylor-Wharton Iron & Steel Co., High Bridge, N. J.

Rawdon, I believe that Mr. Batty's explanation of the formation of the pin holes shaped like melon seeds at the skin of the casting is almost undoubtedly the correct explanation.

We all have seen these pin holes, especially after annealing or after taking a very light cut off a casting; in fact, we have seen them a great deal more often than we wish we had. We know they are entirely distinct from the more or less rounded holes like those in Schweitzer, which we associate with "wild" steel, and do not agree with Mr. Rawdon at all in his criticism of Mr. Batty on that point.

I do feel, however, that in drawing one of the major conclusions of this paper, the wish has been father to the thought. Mr. Batty tells us that pin holes in green-sand castings, especially on re-entrant angles, and embrittlement due to aluminum, are both the result of the penetration of mold gases. The inference is that if sands in green-sand work are so compounded that mold gases do not penetrate into the steel, alumina will not be formed by the oxidation of aluminum by dissociated oxygen (which he postulates as formed by the dissociation of water from the mold), and there will not be what we know as aluminum embrittlement of the steel.

On what particularly existing data, either in this paper or elsewhere, that conclusion is based, I do not see. We have known for twenty-five or thirty years at least, that when steel ingots are cast in an iron mold—in which, of course, there can be no gas penetration—overdoses of aluminum produce aluminum brittleness, particularly in transverse tests.

Anyone who has ever seen many transverse tensile tests pulled from gun tubes or gun jackets of open-hearth steel will be familiar with transverse deficiency in ductility traceable to aluminum. It is well known that aluminum brittleness can be set up by overdoses of aluminum, even in test bars poured into carefully dried core molds from which it is virtually impossible that water vapor should be dispelled from the mold and dissociated, so that Mr. Batty's postulated oxygen penetration could not occur.

I do not believe there is a steel foundryman here who has not seen aluminum brittleness demonstrated in test pieces poured in thoroughly dried cores, and I am sure that a good many here know of careful tests that have been made by adding increasing amounts of aluminum to successive shank-fulls of steel from single heats, pouring the steel in dried cores. Above a certain amount of aluminum, the loss of ductility was pronounced. I have seen probably twelve or fifteen test series, not made in my own shop, demonstrating that in steel poured into dried core molds, aluminum brittleness is set up by overdoses of aluminum.

Now, if aluminum brittleness is set up in steel by overdoses of aluminum when there is no possibility of this mold gas penetration, or very little, how is it possible that simply preventing the penetration of mold gases in green-sand castings will entirely eliminate aluminum brittleness? I can not see it and I cannot see anything in this paper or anywhere else to my knowledge to prove that it is so.

I am aware that Mr. Batty says there are minor sources of aluminum embrittlement, but the major source of the condition he believes to be the

immigrant mold gases. If the aluminum embrittlement I have seen in castings poured in dry-sand molds was due to a *minor* source of embrittlement (the ductility knocked down from 30 per cent elongation and 50 per cent reduction of area in good tests, to 18 per cent and 26 per cent, respectively, in poor tests) I do not know what a minor cause is.

Mr. Batty says that this paper was printed partly to offset what McCrae and Dowdell wrote, that he wrote it to give it to the country at large, through the medium of the A. F. A.; I agree with him. This paper, I cannot help thinking, is a case of special pleading written for the purpose of telling the country at large that in foundries where the green sand mixtures are thoroughly, carefully and properly controlled, aluminum embrittement of the steel does not exist.

It is not for this audience that this paper is written; it is for a different audience, as Mr. Batty has stated. I do not think he has in any way proved his case, and I believe that harm instead of good results from efforts like this to claim accomplishments that cannot be proven.

GEO. BATTY: Mr. Hall's rock has a rounded appearance, and does not hurt, really. I think I admitted, in reading the summary, I had indications that I would have to make some partial retraction.

Some recent investigations have shown that a careless addition of aluminum to the pouring ladle, as the metal is flowing from the large ladle into the hand shanks, may cause pollution to a quite serious extent of the steel in the hand shanks. The aluminum bobs up to the surface in some cases and burns there. It is actually burning—there is the characteristic flash and smear of aluminum burning on the surface of the steel.

In such circumstances we should be putting into the mold a steel already seriously,—instead of only slightly, contaminated with alumina. It does not occur very often, proportionately; and it is not a very serious matter; but it does take these definitions of mine out of the bounds of absolute regularity. Consequently, I think Mr. Hall's point is well taken.

With regard to the embrittlement of the steel cast in ingot molds, I should like to commend to your notice that both Melmoth and myself have had considerable experience in the making of ingots, and there may be a mold condition that can be considered analagous to the injection of gases from green-sand molds. The analogy is not strict, but chill molds of poor construction, after use readily become pitted by the burning out of the graphite. The pits are oxidized, and no matter how carefully that mold is dressed, by the usual scrubbing and graphiting treatments, one may have in that mold an appreciable amount of oxide of iron, so that when the steel is poured, alumina is formed by the reduction of the oxide of iron.

Also, some of the steels, due to various modifications in steel-making practice, may have various contents of silica or silicates. Comstock makes a very good point when he indicates that the photographs of aluminum-treated steel show alumina smears but practically no silica or silicate inclusion, indicating that the aluminum very rapidly has reduced the silica or silicate. There we would have a source of alumina embrittlement.

Visualize the condition thus: If the foundryman is putting into his pouring ladle from the big ladle a steel contaminated with 0.03 per cent silica and providing sufficient aluminum to reduce that silica, he would be putting into the mold a steel contaminated with almost 0.035 per cent alumina, which would give noticeable embrittlement. My point is that we have not entirely overcome the embrittlement question; but that we have removed a great menace; that we can deliver steels now of seventy thousand tensile and higher with quite good ductility, very much higher than those demanded by certain inspection limits, so that the low ductility is an incident rather than a problem.

At the time that an investigation was undertaken by the Bureau of Standards, it was distinctly a problem, a menace to the sale of the castings after manufacture; and if we have reduced the thing from a "problem" to an "incident," we have substantially cured it commercially. Our injection of mold gases now is only a fraction of what it used to be; we have modified green-sand mold constitution and composition, and I think I might, at this point, comment on what I consider the most important point of the previous paper by Mr. Cole.*

Mr. Cole did not insist that he was propounding a principle, but he is actually propounding a very important principle when he insists that the backing sand or heap sand shall be permeable. That has been one of the items of our investigation, and it has predicated our procedure to quite a large extent.

We insist that the backing sand or heap sand shall be at least as permeable as the facing. It is no use making a beautifully permeable facing and surrounding it with an impermeable envelope.

I believe that Mr. Cole's point is a very important one. What we have to do is to examine facts and correlate them to produce principles, and from those principles evolve formulas which are workable.

The embrittlement resulting from the penetration of mold gases was the most important factor inducing this embrittled condition, and I do not agree with Mr. Hall when he indicates, by inference, that the embrittlement is proportionate to the amount of aluminum. The McCrae-Dowdell paper indicates that, with an increase of aluminum from four ounces to the ton to two pounds to the ton, a point is reached at about twelve ounces to the ton where the embrittlement is most acute, so that further increased aluminum did not represent increased embrittlement. That may be indicative, I think, of the fact (which I propose to insist is a fact) that the embrittlement is proportionate to the amount of alumina formed in the steel.

Mr. Comstock's point—raised in reference to a previous paper of mine—that alumina promotes the embrittlement by causing a different distribution of sulphides, is quite interesting and I hope to be able to do some work along that line. Comstock sent some photographs which are published as a discussion of a previous paper, indicative of the sulphide distribution in an aluminum-treated steel, and I think Mr. Melmoth said only yesterday, in conversation, that he was doing some work on

* Cole, H. J., *Natural Bonded and Synthetic Sands in the Steel Foundry*, TRANSACTIONS AND BULLETIN, A. F. A., vol. II, no. 8, August, 1931, pp. 162-169.

the low ductility problem in aluminum-treated steel. When we were working basic in England, our sulphur was very low and we did not have any serious low ductility problem when such steel was treated with aluminum.

CHAIRMAN R. A. BULL:[4] In paragraph 37 of Mr. Batty's paper, the author mentions this fact: "Such castings, therefore, would show no sign of pin-hole penetration at internal angles when examined after sand blastings, but cases have come under the writer's notice where castings that appear perfectly sound before annealing have shown a number of pin holes after the annealing scale had been removed." The inference is that these pin holes, ordinarily are observable before annealing.

I do not think that is true: at least, it has not come under my observation. On the contrary, the great majority of pin holes I have seen in steel castings have only been observable after the annealing scale was removed.

I think Mr. Batty has covered some of the points in a very interesting way. He takes this position, if I understand him correctly—the extent to which we may introduce aluminum into steel without giving the aluminum the opportunity to combine with oxygen, to such an extent one can feel free from any injurious embrittlement as the result of that aluminum indication.

GEO. BATTY: To a very substantial extent: the steels I spoke to Mr. Bull about before the meeting were aluminum treated.

A. W. LORENZ:[5] I must support Mr. Hall in some of the statements which he made in reference to the results obtained on dry-sand molds. All of the test bars which we have ever made have been made in dry-sand molds. We have made numerous tests with and without aluminum, and we certainly were able to get embrittlement in dry sand molds.

A group of about nine foundries in the Milwaukee district combined several years ago for a research investigation, and in the course of that investigation it was necessary that they should furnish test bars indicating the condition of the steel as they manufactured it at the inception of the research. Some of these foundries used aluminum and some did not. All of the test bars were dry sand. The presence of embrittlement in some of the bars was very noticeable.

Some time afterward it was decided to see what results could be obtained eliminating aluminum, so the same foundries first devised a standard test bar and standard method of pouring. As a result all of the test bars submitted in the second lot came out with good ductility figures, reduction of area from 45 to 60 per cent.

In view of this it seems to me that possibly the question of moisture has been somewhat overemphasized. Mr. Batty has stated that one might still have this trouble resulting from oxidation of aluminum due to the method of addition, but I do not feel that this reason could hold in all the above instances. Aumimum was added in the various manners and, regardless of the method by which it was added, some effect could be

[4] Director, Electric Steel Founders' Research Group, Chicago.
[5] Metallurgist, Bucyrus-Erie Co., South Milwaukee, Wis.

noticed as compared with the results obtained when no aluminum was used.

GEO. BATTY: I omitted to reply to that point when I was replying to Mr. Hall, and I think that Mr. Lorenz' testimony is merely evidence that aluminum has to be added very carefully to the pouring ladle. Unfortunately, I have not elaborated on that point, because in our own foundries we have given very great attention to the method of adding aluminum to the pouring ladles, and have eliminated in general any serious oxidation of aluminum in pouring ladles.

Probably I have been arguing on this question of injecting mold gases from what is an unreasonably high standard, that is, the standard of treatment of the metal before it enters the mold. We have been taking means to prevent the oxidation of aluminum in the pouring ladles, and I have come to look upon that as being part of our practice, whether it is general practice or not.

Undoubtedly, one can get many examples of alumina embrittlement; I quote that rather than aluminum embrittlement—in test bars poured into dry-sand molds—but I suggest, in many cases, because of the method of adding aluminum, that the embrittlement-producer was formed outside the mold. There actually is being poured into that mold hot metal contaminated with alumina.

Our standard test mold is used to convince some people that the pin-hole trouble, in its relation to the problem of low ductility, comes from the green sand. That test mold is constructed with one dry-sand shoulder and the rest green sand, and, with a steel untreated with aluminum and poured rather hot into an obviously unsatisfactory green-sand mixture, we would get pin-hole penetration from the green-sand shoulder only; none from the core. We took that as evidence that the green sand was injecting very much more gas than the core.

There is an alternative, that the injection of some core gases may take place a little more quickly than the injection of gas from green sand because of the difference in the chill effect of green sand as compared with dry core.

I concede that both Mr. Hall and Mr. Lorenz have a very substantial point here, but I think my basis was different from theirs, because for three years we have been operating under good green-sand conditions and have eliminated some of the previous variables that were very significant. We now are working on the remainder of this problem to try and make our green-sand tests as good as our dry, and our dry sand tests better than they have ever been.

H. H. BLOSJO:[6] This past year I ran some forty different tests on forty different heats. These heats were all run identical, so far as furnace procedure was concerned; that is, the charge was the same, the melting time was approximately the same, and the slags had about the same consistency, as closely as they could be regulated.

These heats were all given their final deoxidation with aluminum. The aluminum was added in the tea-pot ladle as the melt came out of

[6] Metallurgist, Minneapolis Electric Steel Castings Co., Minneapolis.

the furnace, and the test bars were poured approximately ten minutes following the aluminum addition to the tea-pot ladle. No further addition of aluminum was made to the shank ladle. The bars all were poured in well-prepared, dry-sand core blocks, the sand in this case was the same throughout, and the procedure of making the pours was identical throughout.

I find that we get an extremely great variation in the ductility of the steel; that is, in some cases, with the same tensile strength, we have only half the ductility we had in other cases, and I do not believe that this low ductility is the result, to the greatest extent, of the mold gases coming into the metal, or the deoxidation of mold gases. It is due, in my opinion, to the condition of the metal at the time of the addition of the aluminum.

I have done a little work and found, in the case of a metal that was deoxidized by different methods in the furnace—that is, before the final deoxidation with aluminum—that different properties have been obtained in the final test bars. In my opinion, the properties are due more to the condition of the metal before the aluminum is added than to the mold conditions. We added about a pound of aluminum to the ton of metal, or about 0.05 per cent.

GEO. BATTY: Aluminum of 0.05 per cent is competent to reduce a considerable amount of silica and form a very deleterious amount of alumina in the metal before it actually enters the mold. I touched on this point in the discussion of Mr. Melmoth's paper when I spoke of the care exercised in transferring electric steel from the electric furnace to the mold, as compared with the open-hearth furnace.

In the electric furnace, the operator often taps into a dirty ladle. I have missed that point in my presentation of the subject, because we have adopted a definite standard of cleanliness in the operations of transferring the steel from the furnace to the mold.

These are important operations, and I think these points all have to be looked after very carefully, as it is established that aluminum will promptly reduce silica or silicates and form alumina, whereby there will be put into the mold a steel contaminated with alumina.

This means that we must give to our practice something that may have been neglected; the cleaning of the ladle used in an electric foundry is very important. The addition of aluminum in the ladle itself, as the metal is coming from the furnace, is open to a great deal of criticism in many cases.

In our own practice, when aluminum is added to the large ladle, we wire the aluminum strongly to a heavy rod. The metal is taken from the furnace from below the slag; that is, the taphole is plugged, the furnace is tilted so that metal will flow, and all the metal flows before the slag comes. In this way we prevent a supplementary contamination of the steel with slag and so avoid a potential source of alumina formation. As soon as the slag begins to flow from the furnace, the aluminum, heavily wired, is plunged to the bottom of the ladle, and I believe that avoiding contamination of the steel in transferring it from the furnace to the mold is quite significant.

J. H. HALL: The problem of alumina embrittlement goes a great deal farther, as I see it, than mold gas penetration, and it goes considerably farther than the cleanliness of steel. I have a certain amount of information that will prove both those points, but before touching on them I want to refer to the claim Mr. Batty said he heard made, that they never had this same pin-hole trouble with converter steel before they got acid electric furnaces. I wish I knew who told him that; I would take off my hat to him as the leading Ananias of my experience.

GEO. BATTY: I stated I had examined some of those castings and found there were pin holes.

J. H. HALL: Mr. Batty exhibited his usual high intelligence by stating that he was quite sure that was not the case. Acid converter steel is just as subject to this pin-hole trouble and the low ductility problem as is acid electric steel.

A few years ago I thought I had defeated this low ductility or aluminum problem in our converter steel. With the usual addition of aluminum to the ladle when the heat was being poured off, we took a test coupon poured within the first three minutes after we filled the ladle—I am talking about dry-sand coupons now—and we would have perfectly rotten ductility; the elongation and reduction of area would be simply vile. A second test from the same heat, with absolutely no other addition but poured 15 or 20 minutes later, would give very good ductility.

I thought I had the problem licked—that it was simply a question of temperature and possibly floating out of the alumina, and that if I just waited the proper length of time before I poured my coupons, everything would be satisfactory. However, it was not; I still got occasional law ductility coupons. Mr. Batty, I think, truly says that it is no longer a major problem but an incident. In my experience it has never been anything more than an incident.

Then I thought, having an Ajax Northrup laboratory furnace, that I would make some really clean steel and see if aluminum would make it brittle. We prepared heats of 0.25 carbon steel in an Ajax furnace, making the metal out of Armco ingot iron with very carefully controlled additions of silicon and manganese. The heats were very free from oxide and other inclusions, but a sufficient dose of aluminum would make that steel brittle; that is, it would greatly reduce its ductility.

I also found that it is a fact that when coupons are poured very hot from steel which exhibits aluminum embrittlement, it shows a woody fracture in the bend bar, the result of dendritic structure. Again I thought I had a sure test of aluminum embrittlement. Coupons poured very hot with dendritic structures were the ones that would have low ductility; but that was not so. A bar showing woody fracture on the bend might have low ductility and might not, and a bar which did not show a woody fracture might have low ductility and might not.

Dr. Lucas, of the Bell Telephone laboratories, was at that time our consultant, and after we had cleaned up a few problems on twelve per cent manganese steel, examining specimens at diameters up to 3500, I interested Dr. Lucas in this question of the low ductility problem in

carbon steel. I am well aware that aluminum embrittlement is ascribed to the presence of very finely divided alumina. However, when Dr. Lucas examines steel at 3500 and even 5000 diameters, the alumina must be very fine if the microscope does not distinguish between a low ductility piece of steel and one that is not; and it did not. As a result, we gave up that slant, as we could not prove—we worked hard on it—that the ductility varied with discernible amounts of inclusions, even working up to 5000 diameters.

I have a suspicion that it is not alumina but aluminum that makes this trouble. One of the things that makes me think so is this: I have seen a series of tests poured in which increasing amounts of aluminum were added to successive shank ladles of metal from a single heat, and the more aluminum that was added, the greater the reduction of the ductility.

Moreover, the loss of ductility with increased aluminum additions continued beyond any point where one could possibly suppose there was any further oxidation of aluminum to alumina. For instance, the successive additions were two ounces, four ounces, and six ounces; when as much as six ounces were used, one could not suppose that that six ounces had not reduced all the oxides that were present, but if the addition was increased to eight, ten, or twelve ounces, there was a steady loss of ductility. How could there have been any further alumina formed after a certain amount of aluminum had been added, to account for that further loss of ductility?

I used to be a microscopist when I first left college, and I noticed in those days that everything the microscopists could not explain they said was due to dirty steel. Dirty steel was the favorite explanation for unexplained brittleness, the "dirt" generally being blamed on alumina produced by additions of aluminum.

The microscopists love to explain the low ductility of a sample of steel by the type of arrangement of the inclusions, and are inclined to overlook the fact that frequently one can find several different arrangements of the inclusions in a single sample of steel. That reminds me of a remark I once heard Howe make—that the microscope is an instrument that enables the investigator to "see what he is trying to see," and that one must be cautious in interpreting microscopic evidence.

Nowadays, those who are inclined to blame all the evils to which steel is heir on "inclusions," have taken refuge in the sub-microscopic and lay aluminum embrittlement to inclusions too small to be visible under the microscope. It is difficult to prove them wrong, of course, but I have a feeling they are working the alumina theory to death, and that, if they would try the aluminum theory for a while, they might fare better.

C. E. SIMS:[7] The mechanism of the formation of these pin holes as explained by Mr. Batty seems to be quite well substantiated. There does not seem to be much chance for argument in that direction. The shape and position of these pin holes seems to substantiate his claim.

They undoubtedly are formed by immigrant gases from the mold, but

[7] American Steel Foundries, Indiana Harbor, Ind.

I have wondered sometimes as to just at what stage they were formed. They seem to penetrate the steel quite readily. If the steel was liquid when they were formed, they would float away, and they could not form if the steel was solid—the resistance would be too great. They must be formed somewhere in between those stages.

These gases replaced a certain amount of steel when they force their way in. If the steel is partially solidified at the time they are formed, it must be presumed that the mold is full, and in order to replace that steel it would have to be forced some place else; it will not compress. I understand from the author's description that the main source of gas in this case is water vapor which is dissociated, the hydrogen being absorbed by the steel, and that the gas forming the hole presumably is oxygen.

I cannot agree with this. In the first place, the temperature is not high enough to dissociate water vapor. On the other hand, water vapor at that temperature is an excellent oxidizing medium for steel. Any oxygen present, even as water vapor, would unite readily with the steel. The amount of gas in one of those pin holes is extremely small by weight, and the reaction would be extremely rapid.

The author says that hydrogen is absorbed by the steel. This I do not think is true. The hydrogen atom diffuses very readily through the steel at low temperatures. It is rather insoluble in steel at high temperatures, and is driven out. The hydrogen molecule is not absorbed by steel at all.

I prefer to think that the gas in these pin holes is hydrogen and water vapor, the oxygen being absorbed by the steel. Practically all these pin holes show either iridescence or black surface.

Going back to the first assumption, that the steel is rather viscous when these are formed, because they are held in place when they are formed (sometimes they are at right angles to a vertical surface), there is a chance that the endothermic reaction of the water vapor with steel to form iron oxide causes a little cooling at that point, which solidifies a shell around the gas pocket and tends to hold it in position. As regards the embrittling effect, if the steel is plastic at that time and the oxygen is absorbed, it is too late for any diffusion or conduction or anything else to take place that could possibly affect the steel anywhere except immediately adjacent to this pin hole. A portion of the steel remote from the surface could not be affected by this absorbed oxygen.

At this time I want to tell of an experiment I performed with acid open-hearth steel. I had four sets of molds made up: (a) dry-sand molds thoroughly dried; (b) dry-sand molds improperly dried, about half the ordinary drying time being allowed; (c) green-sand molds skin dried, and (d) green-sand molds in which, just before they were closed, a fine spray of water was spread over the surface, the idea being to get extreme conditions.

These molds then were poured consecutively from the same heat, in pairs. The first of each pair was poured without any aluminum addition. The second had aluminum to the amount of approximately one pound per ton added to the stream of metal in the pouring cup. Standard test block molds were poured with two coupons each, about 14 inches long.

These blocks were examined for pin holes and were heat treated and broken for physical tests.

The dry-sand mold which was improperly dried and to which aluminum had been added, had the worst pin holes, worse than the green-sand mold which had the water sprayed on it. That may be only incidental.

The physical tests showed that all the steels to which no aluminum had been added were so nearly identical that there was no choice at all between them. All of those to which aluminum had been added, whether in dry sand or in green sand, also were exact duplicates of each other; there was not more than a few per cent difference in any case, no essential difference at all.

The reduction of area was the factor affected most. All of the reductions of area in the aluminum-free steels were above 50, and all those in the steels treated with aluminum were below 40.

The very short time before solidification when the aluminum was added, seems to preclude any possibility that gases from the mold should have been a deciding factor in the reduction of ductility. This only substantiates numerous other observations in which the ductility has been reduced by aluminum without regard to mold conditions. On the other hand, we find that the same addition of aluminum to different heats has an entirely different effect on the ductility.

Frankly, I believe that there is almost no relation between the pin-hole trouble and the embrittlement. There is considerable effect caused by the condition of the steel when the aluminum is added. I will not go into that any further at present.

Let me say, too, that open-hearth steel is not free from pin-hole trouble, and aluminum is not a cure-all for pin-hole trouble in any steel. However, it does seem to help the condition a little.

I want to make a few remarks in connection with Mr. Hall's last discussion. I have made about five hundred heats in an Ajax high-frequency induction furnace in 60-lb. and 100-lb. charges, and I cannot conceive, as a result of my observations, where he got the idea that this type of steel is any cleaner than any other type of steel. I have not found it so.

I have been unable to see any essential difference in cleanliness in the amount of true inclusions. By this, I mean those inclusions which are the direct result of deoxidation processes, as against accidental inclusions of slag, sand, etc. It compares very well with open-hearth steel or ordinary electric-furnace steel. These inclusions are a normal condition in steel. No one has yet shown any means of eradicating them.

As regards the relation between microstructure and ductility, here again I must take issue with Mr. Hall. One does not need to go as high as 5000 or 3000 diameters; 100 diameters magnification is sufficient to show the relation that exists between the microstructure and the ductility of steel.

I will be so bold as to state confidently that, in a large majority of cases, I can look at a polished unetched specimen at 100 magnifications and predict whether it will have a satisfactory ductility or not. One does not have to look for sub-microscopic inclusions, nor even to con-

sider them. It is not in relation to the amount of inclusion but to their character and their distribution.

When globular inclusions are distributed indiscriminately through the steel, a good ductility can be expected. If there are very small inclusions that form in little chains and which, when examined more closely, are found to form envelopes around the primary crystals, it will be found that that steel has poor ductility.

This latter type of inclusion is very typical of the effect produced by aluminum. Aluminum, however, is not the only element that produces this type of inclusion, but there is a distinct relation between microstructure and ductility.

J. H. HALL: I do not want to take up too much time stating my position in this matter. I only spoke of 3500 and 5000 magnifications so as to indicate that Mr. Lucas and I took a rather good look at what is ordinarily the sub-microscopic. We also worked at 5 diameters and at 100 diameters.

Mr. Sims has made the absolute statement that it is generally possible to look at samples of cast steel at 100 diameters and predict from the appearance of the inclusions which is the low ductility steel and which is not. I congratulate Mr. Sims on that, because I have never been able to do it.

I have repeatedly taken 12, 15 or 20 tests, some of which were from low-ductility steel and some from high-ductility steel, mixed them all up and said, "Now, I will not 'kid' myself; I will spend an hour and a half or two hours, and by the microstructure alone I will sort these into the ones which have a type of inclusion which means low ductility and those which have a type which means good ductility."

I have examined them slowly and carefully, sorted them without looking at the numbers, and then checked them up with the tests, and have found in every case that I was just fifty-fifty right. Of those which, according to their microscopic structure, should have low ductility, half did and half did not have it; and exactly the same thing applied to the other sets—the sets which by their inclusions should have good ductility—half did and half did not.

I have checked myself that way three or four times. If I am wrong and Mr. Sims is right, I am the poorest microscopist that ever went into the steel foundry business.

GEO. BATTY: I want to thank Mr. Sims for what he has said, but I want to go over his statement more carefully before replying to it.

With regard to Mr. Hall's assertion of increasing embrittlement with increasing aluminum content, here again we have different results from different workers. McCrae and Dowdell have a diagram showing the effect of aluminum additions on the reduction of area and elongation, but, with no aluminum in this particular heat of steel, the reduction of area was about 52 per cent and elongation 30 per cent. With one-quarter pound of aluminum to the ton, the reduction of area was 32 and the elongation 30 per cent. With three-quarters pound of aluminum to the ton, the reduction of area had fallen to 20 per cent and the elongation to about 13 per cent.

Increasing the aluminum to one pound to the ton gave test bars showing 30 per cent elongation and 18 per cent reduction of area. One and one-quarter pounds of aluminum to the ton gave an increase from 30 per cent reduction of area to 32, and an increase in elongation from 16 to 18. Then a little further addition gave a drop.

One and three-quarter pounds was better than one and one-half pounds, and not so good as one and one-quarter. Two pounds to the ton came to the same level, but the low point in reduction of area was at three-quarters of a pound to the ton, and the low point of elongation was at one and one-half to two pounds to the ton.

I have no doubt there will be a good deal more interesting contributions in the written discussion. I am sorry this has taken so much time, but it has provoked a discussion which is desirable.

WRITTEN CLOSURE BY AUTHOR

GEO. BATTY: Neither the amount of discussion nor the nature of the comments upon my paper caused me any surprise, because I have found, in conversation with other steel foundrymen, many diverse opinions—based upon the results of individual series of experiments—concerning what has been labeled the "low ductility problem."

I think it may clarify matters a little if we agree to differentiate between (a) the low ductility problem and (b) the decreased ductility problem. My paper is concerned primarily with the elimination of the low ductility problem, and any careful reader of the paper must concede that I do not claim to have solved, as yet, the problem of depreciated ductility resultant upon the treatment of steel for castings with aluminum as a supplementary deoxidizer. The differentiation between the low ductility problem and the decreased ductility problem is essentially one of degree.

The low ductility problem may be considered relating to such a degree of embrittlement as made the steel incapable of meeting certain physical test specifications, while the decreased ductility problem is incidental to the manufacture of castings which are commercially acceptable on the basis of physial test results.

Because of the nature of some of the comments on my paper, I think it is well to repeat here a part of the abstract: "It is not disputed that steel treated with aluminum will, under conditions inevitably involving oxidation, be less ductile than an identical steel having no aluminum addition."

My opinion is that the embrittlement of aluminum-treated plain carbon steel for castings is closely related to the amount of involved alumina. On such an assumption—the examples being based on published work of Comstock; McCrae and Dowdell; McCrae, Dowdell and Jordan; some unpublished work by Melmoth, and my own investiga-

tions—we are forced to examine the factors involved in the process of making a steel casting which may promote the formation of alumina.

In order of occurrence we may list these as follows:

(1) Inclusions in the metal which are the direct result of the primary deoxidation process employed.

(2) Contamination of the steel with silica or silicates in the tapping operation or in the ladle.

(3) Oxidation incidental to the transference of metal from large ladle to pouring ladle and from pouring ladle to mold.

(4) Oxidation within the mold.

(*1*) The general product of the acid electric furnace making steels for castings contains between 0.03 and 0.06 per cent silica existant as siliceous non-metallics, usually in a fairly fine state of division. Such a steel normally produces physical test results that are considered good, in that the "strength" part of the specification is satisfactorily met and the "ductility" part of the specification is met with a liberal reserve of both elongation per cent and reduction of area per cent over the specified minima.

We find, therefore, that we have a good, even an excellent, degree of material commercially which is metallurgically defined as "dirty." Notwithstanding this fact, metallurgists and steel makers are constantly striving to produce cleaner steel with a view to producing superior physical properties in the ultimate commodity.

I believe that cleanliness, in respect of oxides and siliceous non-metallics in the steel, is more important in steels which have to receive an aluminum addition than in steels which do not have to receive aluminum as a supplementary deoxidizer. The importance of the amount of suspended oxides and silicates will later be commented upon in my reply to Dr. Dowdell's written contribution to the discussion.

Several of the contributors to the discussion have insisted that the embrittlement following upon the use of aluminum as a supplementary deoxidizer is related primarily to the original condition of the steel. I readily concede that the condition of the metal as delivered to the ladle from the furnace is a significant factor, as also is the degree of cleanliness observed in ladle preparation and in avoiding the involution of furnace slag in the tapping operation.

I would insist, however, that if proper control is exercised in performing the deoxidizing operation in the furnace, and in avoiding serious contamination of the metal by non-metallics in the transference operations, the amount of normal deoxidation products and of involved non-metallics should not be sufficient to promote, upon the proper addition of 0.05 per cent aluminum, so much remanent alumina that the steel is embrittled to such extent that it comes within the range of "low ductility," producing results of elongation per cent and reduction of area per cent incompetent to meet the desired physical test minima.

Normal deoxidation products and involved siliceous non-metallics promote the formation of embrittling alumina upon the addition of aluminum to the metal. If the embrittlement of the metal is promoted

by alumina and is, to any extent, proportionate to the involved alumina, it must be conceded that the amount of oxides and silicates present in the steel at the moment of aluminum addition may be a significant factor. In conditions of good practice, however, they are not necessarily a serious factor, as is evidenced by the tables of test results quoted in the paper.

(*2*) It is a simple matter to devise means adequate to prevent any serious intermixing of slag and metal during the tapping operation, but constant care and supervision must be exercised in order to insure that the large ladle is delivered to the spout in a properly clean condition.

(*3*) Transference of metal from large ladle to pouring ladles and from pouring ladles to molds may involve a little oxidation of the metal. However, in a steel containing a powerful deoxidizer such as aluminum, the products of such oxidation as a rule are not serious. If aluminum is carelessly added to the metal in the pouring ladles, some serious and wasteful oxidation of the aluminum occurs and at the same time decreases the amount of free aluminum in the metal as it enters the molds, thereby decreasing the ability of the metal to resist pin-hole formation by immigrant mold gases.

A dirty hand shank or pouring ladle—that is, a pouring ladle smeared internally with solidified metal oxidized on its exposed surfaces—is bound to promote the formation of the oxide of any readily oxidizable constituent in the succeeding lot of metal in such ladle.

Under the foregoing three headings I have briefly referred to factors outside the mold competent to produce alumina when aluminum is added to the metal.

In considering the low ductility problem it should be stated that, when considerable care was exercised to guard against alumina contamination from the causes listed in the subheadings (1), (2) and (3), low ductilities—as distinct from depreciated ductilities—were experienced as a result of poor condition of the molding sand. By bringing about and maintaining what was believed to be a satisfactory condition of the molding medium—and of the complete molds—the low ductility problem (as distinct from the decreased ductility problem) was substantially eliminated in our foundries.

(*4*) The pin-hole trouble was manifest for years in light steel castings produced in green-sand molds, and, with very few exceptions, it was found that this pin-hole trouble could be cured by using aluminum as a final supplementary deoxidizer. Incidental to the use of aluminum as a supplementary deoxidizer, the low ductility problem came into being and has remained more or less of a problem in the production of green-sand castings.

It is the experience of all foundrymen with whom I have discussed this matter, that aluminum—or some other powerful supplementary deoxidizer—must be used in the steel when producing light steel castings in straight green-sand molds. It also is generally acknowledged that for dry-sand castings—and in some cases for castings produced in skin-dried molds—it is unnecessary to use a supplementary deoxidizer in order to prevent the formation of pin holes. The pin-hole trouble has been associated, almost generally, with green-sand practice, and the low duc-

tility problem has been associated, almost generally, with aluminum-treated steels in green-sand practice.

The degree of embrittlement—using a test bar produced from the heat, untreated with aluminum, as a standard of comparison—is, in my conception, divisible into two parts. One part of the embrittlement is attributable to the formation of alumina by reaction with oxides or silicates in suspension in the metal. The other part of the embrittlement is due to the oxidation of aluminum within the mold by immigrant mold gases.

These are the two major causes, and some small and relatively insignificant minor causes have previously been noted, above. The magnitude of the embrittlement attributable to the first-named major cause must be related not only to the amount of the oxides and silicates suspended in the metal but also to the procedure of adding aluminum to the metal, and also to the time of aluminum addition in relation to the actual pouring time.

It is indicated, therefore, that a fairly definite technique must be employed in the making of the steel and in safeguarding it from siliceous contamination in transit from furnace to mold. However, it is significant, in my experience, that when what is believed to be good practice has been followed in the production and safeguarding of the steel, a serious degree of embrittlement has resulted upon producing test coupons in an unsatisfactory molding sand.

Such a condition of molding sand was apparent—in the physical test results accruing from these samples—not in one foundry but in several foundries coming under my observation, and in each case it has been found regularly practicable to meet physical test specifications, with an adequate reserve of all the physical requirements above the specified minima, by modifying only the composition and constitution of the molding medium. In achieving this result it is conceded that, as a general rule, the ductilities—particularly in respect of reduction of area—of the aluminum-treated steels were somewhat below those of comparison samples poured from the heat untreated with aluminum.

It is this partial embrittlement—or decreased ductility—which is our remanent problem, but I insist that the elimination of a serious tendency of the molding medium to inject mold gases into the casting has substantially overcome the hazard of rejections—in respect of low ductility; ductility so low that it would not meet certain physical test specifications.

In my experience—and I readily concede that the experience of no one individual may be assumed to cover the bounds of possibility—the interrelationship of the pin-hole trouble and the low ductility problem is established. Further, at the time the paper was written I had secured indications regularly that some embrittlement was inevitably involved as a result of the ordinary method of adding aluminum to steel of such a composition, and subject to such treatment in transference to sand molds, as is customary in a steel foundry.

This embrittlement is most probably due to the alumina (or aluminates) produced by the reaction of aluminum with such primary deoxidation products as are normally present in normally good steel. In addition, the care exercised in making the aluminum addition must have

some bearing on the degree of embrittlement in proportion to the amount of alumina formed as a result of the direct oxidation of aluminum at the surface of the metal.

In my discussion of Melmoth's paper, "Variables in Steel Foundry Practice,"* I indicated what I considered the safest method of adding aluminum to steel in order to avoid dangerous and wasteful incidental oxidation of the aluminum. Such practice is regularly followed in most of the foundries with which I am associated, and it is our experience that a serious degree of embrittlement may be resultant upon a careless addition of aluminum to the hand shank as it is receiving metal from the large ladle.

For instance, 2½ grams of aluminum in the form of a half-inch rod is appreciably more liable to produce a serious degree of embrittlement when thrown into a hand shank—during the process of filling the shank—than is 20 grams of small aluminum shot added at a similar time to a similar amount of metal. The half-inch rod, being bulky as compared with the small pellets, persists in floating on the surface of the metal and oxidizes considerably. It actually can be seen "burning."

In the foregoing paragraphs I believe I have replied to several of the points raised in the discussion, and again I wish to be explicit—even at the risk of appearing prolix—by repeating that "It is not disputed that steel treated with aluminum will, under conditions inevitably involving oxidation, be less ductile than an identical steel having no aluminum addition."

In replying to Mr. Rawdon's discussion of my paper, I would say that my objection—and the objections of a number of other steel foundrymen—to the McCrae-Dowdell paper† was concerned essentially with the proposition that a comparatively "weak" steel seemed necessary in order that adequate ductility properties be secured to meet the particular physical test specification that was adopted as test in their work.

The tables in my paper show that steel is regularly being made which adequately meets the ductility requirements of Navy-B specification and at the same time has considerably more strength than is indicated in such specification. I say that such steels are regularly being made—not only in the foundries with which I am associated, but in many other foundries—because some objection has been taken to my citation of heats not strictly consecutive. I think I may cover such an objection by stating that since the middle of 1928 I have no record of any heat submitted against Navy-B specification failing to pass.

Most certainly I have no wish to deprecate the actual work of my friends McCrae and Dowdell, but would suggest it was unfortunate that their talents and energies were expended upon material of a type that so soon ceased to be representative of the product of a reputable foundry.

My insistence upon the importance of sand condition as a contributory factor—seriously contributory—to the embrittlement of aluminum-treated steel was based almost entirely upon my experience in American foundries operating acid electric furnace practice and producing green-

* TRANSACTIONS, A. F. A. (1928), vol. 36, pp. 323 and 801-812.

† McCrae, J. V., and Dowdell, R. L., "The Effect of Deoxidation and Mold Conditions on the Tensile Properties of Carbon Steel Castings"; *Transactions*, A. S. S. T., vol. 18, p. 159, 1930.

sand castings. In Great Britain I had operated both basic electric and acid electric but, because of good sand condition, had not experienced any real problem, in respect of securing adequate ductilities, such as I met with in this country. Proper sand control, so far as I am concerned, has so mitigated the embrittlement effect in aluminum-treated steels as to have removed them from the range of the low ductility problem.

To the actual mechanism of the formation of pin holes we must apply, I think, the postulates of some substantial evidence. We can never actually see them formed, and I will readily concede to Mr. Rawdon or to anyone else that we do not definitely know the actual sequence of occurrences that produce the pin holes.

My suggestion of the mechanism of the formation of pin holes appeals to some steel foundrymen, while others do not agree. I have been told of one experiment in which a molding sand was used containing 10 per cent moisture; in this sand, castings were produced which were free from pin-hole penetration. It is conceivable that such a sand, particularly if the mold face was of a fine texture, exerted what was an abnormal chill effect upon the metal and so produced an initial envelope of such strength as to resist the pressure of mold gases.

Another seeming anomaly in reference to this question of pin holes is that coarse-grained sand of high permeability has been found more prone to produce the pin-holed condition than finely grained sand of appreciably lower permeability.

In reply to the written discussion by Dr. Dowdell, I would say that the high properties given in Tables 1, 2, 3 and 5 of my paper represent something probably a little above the average of the tests in the records of the foundries from which the particular examples were taken. I may add, however, that I should have no difficulty in extracting from such records lists of test results somewhat better than those already quoted. Particularly is this so in the past few months. I would also say that we do not experience considerable difficulty in producing regularly castings which will meet Navy-B specification, and that our sand control is by no means elaborate—it is merely careful and regular.

As to the inference drawn from some paragraphs in my paper, I would say that the original investigators must have been aware of the fact that mold materials had to do with the question of pin holes because the problem concerned the product of foundries which, in total, produced castings by the dry-sand, skin-dried and green-sand methods. I held the view, however—and urged it strongly—that an adequate commercial mitigation of the low ductility trouble could readily be secured by producing a proper and controlled mold condition.

The McCrae-Dowdell paper definitely indicated some embrittlement of steel resultant upon aluminum additions even when the steel was poured into molds composed of dried cores. This embrittlement is believed to be resultant upon the presence of the reaction products of aluminum and the normal impurities in plain carbon steel.

Some explanation is obviously necessary in reply to Dr. Dowdell's recital of the making of supplementary heats as reported in Table XXA of the McCrae-Dowdell paper. It is rather surprising to me that refer-

ence has been made to the failure of one of the foundries to produce even respectable results from the six heats that were made in the presence of Dr. Dowdell and Mr. McCrae, because I have given to Dr. Dowdell the fullest possible information on this matter, as follows:

"You refer to the heats from one of these three foundries showing a complete failure. This is quite correct, but upon investigation of the procedure of producing the metal—following some information given to me by McCrae—I found that the steel maker at that plant had varied ridiculously from the practice which had been laid down for him as standard procedure. The following is what I found to have happened in the making of the heats which failed so badly:

"The heats were taken down in the normal manner and the boil was killed with wash metal. The final additions of ferrosilicon and ferromanganese were then added. At this point the operator commenced his inspired variations. In order to thin the slag so that it would run cleanly from the furnace through the tap hole (this is the explanation he gave me), he added a couple of shovels of lime and stirred the whole vigorously. He then tapped the heat and, when about a ton of metal was in the ladle, threw in the following mixture:

A few pounds of ferromanganese,
A few pounds of ferrosilicon,
2 lbs. of aluminum, and
2½ lbs. sodium carbonate.

"In the first place, he had been most definitely informed that no late addition of lime or limestone should be made to his slag because of the ability of CaO to replace FeO in the slag. The injection of an appreciable amount of FeO to a steel containing about 0.35 per cent silicon is surely likely to produce a good deal of finely divided silica. As the heats were tapped almost immediately after the stirring up of the bath following the lime addition to the slag, there could be very little opportunity for the levitation of the produced silica.

"When the melter added his mixture of ferrosilicon, ferromanganese, aluminum and sodium carbonate to the open metal in the ladle, he was producing more oxides for suspension in the steel by the burning of aluminum on the surface of the metal.

"This man assured me that he had only used this method on the special test heats as he believed he was thereby taking means to insure the perfect deoxidation of the charge. He actually believed he was doing something good, and he certainly had no right to vary from his normal procedure."

In reply to the comment, "Even with the data given from the two remaining plants, Table XXA is not in complete agreement with the data given by Mr. Batty," it can only be stated that my tables are veritable extracts from the records of our companies, duly certified by inspectors who witnessed the tests.

In reference to my brief quotation concerning opinions on the cause or causes of the so-called over-reduced condition, I hold the opinion that the brief quotation contains the "meat" of the authors' deductions, but obviously any interested individual may obtain and read the paper in

full and determine whether the brief quotation comprises the essential summation.

The reference at the beginning of the abstract of my paper need not be construed as uncomplimentary to the work done primarily by the late J. V. McCrae. Before the McCrae-Dowdell paper was published, both the authors were informed of the opinions of myself and several other interested parties concerning the desirability of publishing data which we believed to be no longer representative of the product of reputable steel foundries. Unfortunately, evidence had to be adduced of the large amount of work that had been done by the authors of that paper, and such evidence took the form of the publication of the compiled results of their work. It is probable that their work was chiefly valuable in indicating, by comparison with later work, that considerable progress had been made in an attack upon the problem of low ductilities in aluminum-treated steels for castings.

The comments which Mr. Sims made on my paper at the time of presentation, were of such an order that I did not care to make an attempt to reply immediately. I preferred to take time to consider various statements he had made.

It pleased me to note that Mr. Sims agreed with the views I expressed as to the mechanism of the formation of pin holes, but it was much more interesting to know that he disagreed with some other aspects of my statements.

It is readily conceded that if the steel is liquid when the mold gases are injected, such gases will float away; and, assuming that the pin holes are formed, as Mr. Sims suggests, somewhere between the liquid and the solid stages, we arrive at a standpoint which is dangerous as the basis of argument if we assume that the gases which formed such visible pin holes were the only gases to be injected into the steel in its progress through and its residence in the mold. I want to make it very clear that I believe remanent pin holes to be evidence of only a part of the gases that have been injected into the metal from the mold. This is important when we come to consider the effect of injected mold gases on steels containing aluminum as a supplementary deoxidizer.

It has been found by practically all the individuals engaged in the manufacture of light steel castings that aluminum is competent to eradicate the pin-hole trouble, but the amount of aluminum necessary to prevent the presence of pin holes in the castings varies with the mold condition. In other words, a mold which will inject a large amount of mold gases or vapors into the casting will require a large amount of aluminum to inhibit the ability of such gases to form remanent cavities of the type defined as "pin holes."

Bad molds—molds of an inferior type which will inject a considerable amount of gas into the metal—produce an immediately observable boil effect in the metal such as can be seen by looking down a head or riser. Particularly is this boil effect noticeable when the metal overflows an angle of the mold, and in open cast test blocks of the type standard in our foundries, such a boil can be seen—from inferior sand—at the green-sand shoulder as the mold is being filled.

In view of this fact, it is by no means safe to assume that alumina embrittlement will be acutely located in the region normally occupied by pin holes in a steel untreated with aluminum. The boil effect is most noticeable from re-entrant mold angles, but there is no doubt in my mind that a similar (although smaller) boil effect is produced over practically the whole area of the mold during pouring when an inferior molding medium is employed. Particularly may this apply to the gate of a casting where the thermal attack of metal on mold is at its maximum, so that the metal entering the true mold cavity may be considerably contaminated with alumina when an aluminum-treated steel is poured into such a mold.

Such a set of conditions—readily conceivable—obviously results in the prevention of any acute localization of alumina. I believe it is necessary to concede that molds of an inferior type inject much more gas into the metal than is actually assessable by determining the total volume of the remanent pin holes. On such a belief I am prepared to insist that the alumina formed within the mold is not acutely localized near the surfaces of the casting or test block but is distributed throughout the whole mass of metal.

It is suggested, therefore, that Mr. Sims was not arguing from an absolutely correct basis when he stated, "Now as regards the embrittling effect, if the steel is plastic at that time and the oxygen is absorbed, it is too late for any diffusion or conduction or anything else to take place that could possibly affect the steel anywhere except immediately adjacent to this pin hole. A portion of the steel remote from the surface could not be affected by this absorbed oxygen."

We now have to consider what happens to the hydrogen of the injected water vapor which is presumed to be the main cause of pin holes in a steel not treated with a powerful supplementary deoxidizer. By taking two identical molds of the test-block type produced in an inferior sand known to inject mold gases into the metal, and by filling one of these molds with steel untreated with aluminum, filling the other mold with steel from the same heat of metal but containing an adequate addition of aluminum, we produce—as a general rule—one test block considerably pin holed and another test block free from pin holes. It seems reasonable to assume that an equal amount of mold gas was injected into the metal in each mold.

Mr. Sims is quite correct when he insists that the pin holes show either iridesence or black surface, and this is taken as evidence that the water vapor oxidized the interior of the cavity and left hydrogen as the gas inhabiting or occupying the pin-hole cavity. I would not like to attempt to dispute such an assumption. It conforms absolutely with my own views, but if hydrogen is not, as Mr. Sims states, absorbed by steel at a high temperature, the aluminum-treated steel should also contain pin holes inhabited by hydrogen.

We know that such is not the case. We know that as a general rule an aluminum-treated steel is free from the defect known as "pin holes," and we know that aluminum has generally been adopted as a supplementary deoxidizer for the purpose of preventing the incidence of pin holes in green-sand castings.

The problem confronting us now is, where did the hydrogen go? In a steel containing aluminum we know that alumina is formed when either air or water vapor, or both, are injected into the metal. In the case of water vapor, the oxygen rapidly combines with aluminum to form alumina, leaving hydrogen which, if unabsorbed, must produce a cavity either of the pin-hole type or of the subcutaneous blow-hole type.

In aluminum-treated steels, as a general rule, we find no such cavities, and it is inconceivable to me that the hydrogen is forced back out of aluminum-treated steel into the mold. If it is not forced back out of the steel, either a cavity must remain in the steel or the hydrogen must be absorbed either by the iron or by some other constituent of an aluminum-treated steel. I submit that general evidence substantially indicates that the hydrogen of water vapor can be occluded by aluminum-treated steel.

I have insisted upon the interrelationship of the pin-hole trouble and the low ductility problem because aluminum has generally promoted an embrittled condition. This embrittlement, in my experience, is relative in a considerable degree to the mold effect upon aluminum-treated steel, and by adjusting the condition and composition of the molding medium it has been found practicable to produce castings free from pin holes and substantially free from serious embrittlement.

In an earlier part of this closure I have detailed causes outside the mold which tend to promote alumina embrittlement. Yet the fact remains that when generally adequate safeguards are taken to prevent the presence of alumina in the metal as it enters the mold, serious embrittlement can and does result from the injection of mold gases into an aluminum-bearing steel.

The citation by Mr. Sims of a series of experiments poured in various kinds of molds is distinctly interesting, and it is particularly notable that an improperly dried dry-sand mold had the worst pin holes. Most practical foundrymen would have expected such a result to ensue because, as a general rule, a dry-sand mold is of low permeability. Often dry-sand molds are of distinctly irregular permeability because of the grain shape of the sand and the relation of grain shape to the efficacy of a standard method of ramming.

It is not at all surprising that a pin-holed block produced from aluminum-treated steel should have low ductility. The presence of pin holes would seem to indicate that all the aluminum had been oxidized by early immigration of gases, so that no free and active aluminum remained in the metal to oxidize the later immigration of gas which produced the remanent pin holes.

Comment has been made on this citation by Mr. Sims because his evidence has a direct bearing on the proper treatment of steel with aluminum in order to promote the smallest possible amount of alumina contamination. It is desirable—and I believe necessary—to deliver steel to the molds substantially free from alumina contamination so that the only alumina contamination is that which is inevitable as a result of the oxidation of aluminum by mold gases. Obviously, sand condition predicates to a large extent the amount of gas or vapor injected, thereby

predicating in proper conditions the amount of alumina formed in the metal within the mold.

The advocated system of aluminum addition to metal for the production of light green-sand castings is to plunge a block of aluminum to the bottom of the metal in the large ladle and to allow an interval of about five minutes to elapse before the metal is transferred from the large ladle to the pouring ladles. The addition to aluminum is attended by serious risks of contaminating the steel with a considerable proportion of alumina, as has been quoted in an early part of this closure.

The addition of aluminum to the metal in she pouring ladles by throwing a piece of aluminum rod into the pouring ladle while it is being filled, is almost inevitably attended by some degree of oxidation of the aluminum and some degree of embrittlement of the resultant casting or test block.

It is due Mr. Hall to quote two examples referred to in my partial recession concerning the prime causes of embrittlement. Two heats of

Table 6

COMPOSITION

Carbon, per cent	0.20
Manganese, per cent	0.83
Silicon, per cent	0.35

TENSILE TEST RESULTS

	Heat Nos.			
	855-N	855-NA	855-D	855-DA
Yield point, lbs. per sq. in	46,000	44,500	44,000	43,000
Tensile strength, lbs. per sq. in	75,000	72,500	66,000	69,000
Elongation, per cent	32.0	22.0	37.0	25.0
Reduction of area, per cent	53.5	24.4	60.4	31.8

steel were made and were treated with aluminum in the furnace. Heat No. 855 was ored down to low carbon, 0.12 per cent; the boil was kifled with wash metal, carbon raised slightly with wash metal, and 5 pounds of aluminum plunged to the bottom of the bath. The finals—ferrosilicon and ferromanganeses—were then added and the heat tapped after the usual interval of four minutes. The weight of the charge was 5000 lbs.; standard test blocks were poured and produced the results of Table 6.

Heat Treatments

Heats 855-N and 855-NA maintained at 1650 degs. Fahr. for three hours and cooled in air. Heats 855-D and 855-DA maintained at 1650 degs. Fhr. for three hours, cooled in air; reheated to 1260 degs. Fahr., maintained at temperature for three hours and cooled in air.

The material for test blocks 855-N and 855-D received no addition to the pouring ladles. These test blocks were slightly pin holed at the green-sand shoulder.

Test blocks 855-NA and 855-DA received an addition of 14 grams aluminum rod in the pouring ladle. This aluminum rod was thrown onto the surface of the metal in the pouring ladle as it was being filled. That some considerable oxidation of the aluminum occurred was evidenced by the flash and smear of the aluminum on the surface of the metal in the shank.

The material which produced blocks 855-NA and 855-DA was considerably contaminated with alumina before it entered the mold. The oxidation of aluminum in the hand shank was considered abnormal but it of a type and degree that might readily occur as a result of careless addition of a supplementary deoxidizer to metal in the pouring ladles.

Heat 857, 5000 lbs. in weight, was ored down to about 0.12 per cent carbon, the boil was killed with wash metal and the carbon raised slightly with wash metal. The additions of ferromanganese and ferrosilicon then were made. After stirring these additions into the bath, a 5-lb. pig of aluminum was plunged to the bottom of the metal in the furnace, and one minute thereafter the heat was tapped.

Table 7

COMPOSITION

Carbon	0.17
Manganese	0.76
Silicon	0.38

TENSILE TEST RESULTS

	Heat Nos.			
	857-N	857-NA	857-D	857-DA
Yield point, lbs. per sq. in.	45,000	41,000	37,000	40,000
Tensile strength, lbs. per sq. in.	67,000	66,000	60,500	63,000
Elongation, per cent	37.0	27.0	40.0	28.0
Reduction of area, per cent	57.7	31.8	64.8	41.5

The analysis of this heat of metal was reported as in Table 7.

The suffixes applied in the foregoing test results on heat 857 denotes heat-treatment conditions identical with those on heat 855, and aluminum additions to the pouring ladles of 14 grams aluminum to 70-lbs. of metal in the pouring ladles producing blocks NA and DA.

The same serious oxidation of aluminum in the pouring ladles occured with heat 857 as with heat 855. These two heats indicate the serious degree of embrittlement that may be resultant upon the formation of alumina as a result of careless addition to the metal in the hand shanks. It should be noted that 2 lbs. of aluminum per ton had been applied to the metal in the furnace and test blocks 857-N and 857-D showed no evidence of pin-hole penetration, which is considered substantial proof that free aluminum remained in the steel at the time the test block castings were poured.

While the foregoing results do not agree with the citations made by

Mr. Blosjo and Mr. Hall, they are indicative of the fact that what I have come to consider correct practice in respect of making aluminum additions to the steel, and correct procedure in the production of molding sand, are competent to produce green-sand castings substantially free from pin holes and substantially unafflicted with the low ductility bugbear. The test results quoted in my paper, and other results we are regularly obtaining, justify me in my assertion that by proper control of sand conditions it is possible substantially to eliminate both the pin-hole trouble and the low ductility problem.

Effect of Soaking Time on Initial Temperature and Analysis of Cupola-Melted Iron

By W. H. Spencer* and M. M. Walding,† Birmingham, Ala.

Abstract

In order to determine whether or not there is any valid reason for the belief that a soaking time of one to two or more hours is of advantage in cupola melting, a series of tests were run using various cupolas and under varying conditions. The data obtained are given and discussed. The authors conclude that no beneficial results are obtained by soaking the charges for an extended period.

1. The theory often has been advanced that the charging of a cupola from one hour to two and one-half hours before the blast is put on will give hotter and better first iron. This paper deals with a series of tests designed to find the effect of varying the soaking time.

Cold and Hot-Blast Cupolas Used in Test

2. Two of the cupolas used in this test were ordinary cold-blast cupolas, differing only in the diameter of the melting zone. Cupola No. 8 was boshed 2 inches and cupola No. 9 was boshed 6 inches on the diameter at the melting zone. Table 1 gives the dimensions of these two cupolas.

3. Cupolas Nos. 5, 6 and 7 are hot-blast cupolas and a full description of them has been given[1] by J. T. MacKenzie.

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[1] J. T. MacKenzie, *The Moore Hot-Blast Cupola;* Preprint No. 31-23 for May, 1931, Convention American Foundrymen's Association.

Note: This paper was presented and discussed before one of the gray iron sessions at the 1931 convention of the American Foundrymen's Association.

Table 1

DATA ON CUPOLAS NOS. 8 AND 9

Cupola No.	No. tuyeres.	Height of tuyeres above sand bottom, inches.	Height of charging door above tuyeres, feet.	Diam. at charging door, inches.	Diam. at melting zone, inches.	Diam. in basin, inches.	Tuyere dimensions, inches. Inside cupola.	Tuyere dimensions, inches. Smallest place.
8	6	11	14	54	52	54	4 x 21	3 x 15
9	6	11	14	54	48	54	4 x 21	3 x 15

Table 2

DATA OF TESTS OF GROUP 1

(All-steel melt on 48-in. bed; blast 15 oz.; phosphorus 0.4%)

Cupola No.	Soaking time, minutes.	Blast on to 1st tap, minutes.	Temperature, degs. Cent. 1st tap.	2nd tap.	3rd tap.	Analysis of 1st ladle. Si, %	S, %	TC, %
9	150	29	1472	1460	1444	1.50	0.102	3.12
8	15	38	1480	1464	1460	1.74	0.092	3.12
9	5	50	1484	1488	1476	1.42	0.095	3.17
8	105	35	1468	1448	1440	1.57	0.078	3.22
9	105	35	1464	1452	1440	1.57	0.086	3.01

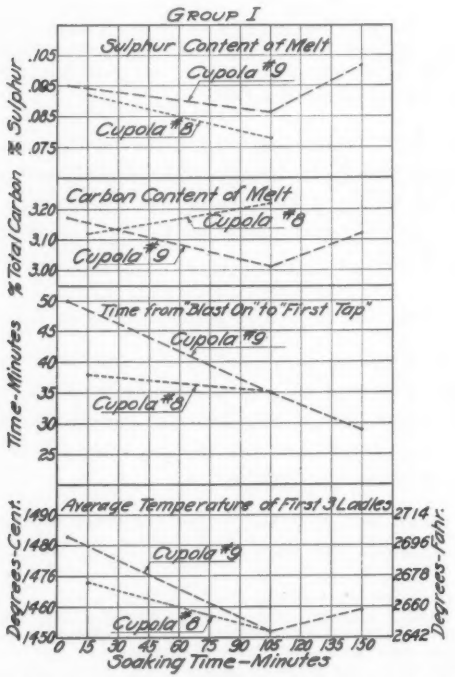

FIG. 1—FIRST GROUP OF TESTS, FOLLOWED BY REGULAR CHARGES. SEE DATA OF TABLE 2.

4. Table 2 gives the results on the first group of tests. The coke was the same kind for all tests. In cupolas Nos. 8 and 9 the same weight of iron, coke and limestone was used in all cases, except in making up the bed. The iron charge weighed 3000 lbs., coke between charges was 300 lbs., the flux was 80 lbs. of limestone on the bed and 60 lbs. between charges. In cupolas Nos. 5, 6 and 7, the total iron charge was 12,000 lbs., the coke between charges 1300 lbs. and the flux was 400 lbs. of limestone with 20 lbs. purite in all tests.

Tests of Group 1

5. The first group of tests was one charge 100 per cent steel with 2 per cent of 15 per cent ferrosilicon, followed by regular charges such as in Group 2. The bed for this series was 48 in. high, burned until red spots were showing through it. These melts were made in cupolas Nos. 8 and 9.

6. These results are shown graphically in Fig. 1. The average temperature of the first three ladles (3000 lbs. each) is used in this graph. Temperatures were read on the stream by means of an optical pyrometer, calibrated by the U. S. Bureau of Standards.

7. The temperature of the stream tends to be lower with longer soaking time. Melting rate, as shown by time from blast to first tap, is more rapid on the longer soaking periods. The average carbon on the two cupolas shows practically no change. The sulphur content of the melt, except for one test, is lower with more soaking.

Tests of Group 2

8. Group 2 is a series of tests in cupola No. 9 on a well-burned 40-in bed. The mixture is 61 per cent pig iron, 26 per cent cast scrap and 13 per cent steel. The blast pressure was 12 oz. and the average phosphorus content 0.65 per cent.

9. Fig. 2 gives these results, using the average temperature of the first three ladles.

10. The melting temperature, time for first tap and sulphur content of melt all show a drop at 105 minutes and a rise at 135 minutes soaking time. Carbon content gives a gradual rise with soaking time increasing in length. It will be noted that Group 1 gave very similar curves for temperature and sulphur content.

Tests of Group 3

11. Group 3 consists of melts of 50 per cent steel and 50 per cent pig iron on a 48-in. bed. Thirty-eight inches of this bed was well burned and 10 inches of fresh coke was added just before the first charge. Blast pressure on these melts was 15 oz. and phosphorus content 0.45 per cent. Cupolas Nos. 8 and 9 were used for these tests also.

12. In this group the average temperature for both cupolas

Table 3

DATA OF TESTS OF GROUP 2

(Pig iron mixture on 40-in. bed; blast 12 oz.; phosphorus 0.65%)

Cupola No.	Soaking time, minutes.	Blast on to 1st tap, minutes.	—Temperature, degs. Cent.— 1st tap.	2nd tap.	3rd tap.	—Analysis of 1st ladle.— Si, %	S, %	TC, %
9	135	30	1428	1440	1436	1.55	0.076	3.60
9	15	38	1420	1436	1424	1.57	0.065	3.57
9	105	25	1416	1424	1420	1.63	0.062	3.59

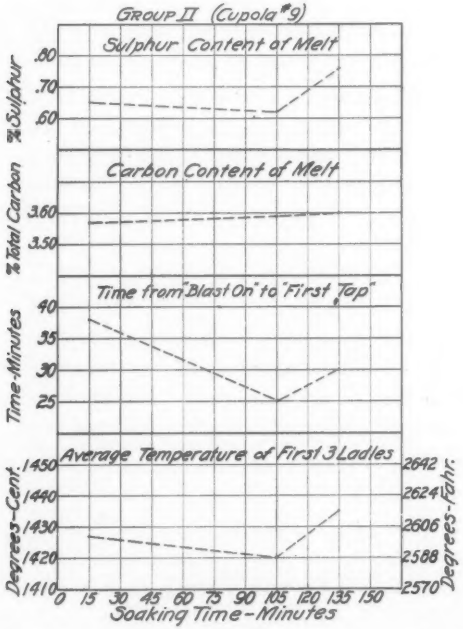

FIG. 2—SECOND GROUP OF TESTS. SEE DATA OF TABLE 3.

shows a slight drop with the longer soaking time. The melting rate, as in both previous groups, is more rapid for the long-soaked charges. The carbon and sulphur content is very erratic, due no doubt to the mixture consisting of 50 per cent each of such widely different materials as pig iron and steel.

Table 4

DATA OF TESTS OF GROUP 3

(50% pig and 50% steel on 38-in. plus 10-in. bed; blast 15 oz.; phosphorus 0.45%)

Cupola No.	Soaking time, minutes.	Blast on to 1st tap, minutes.	—Temperature degs. Cent.— 1st tap.	2nd tap.	3rd tap.	—Analysis of 1st ladle.— Si, %	S, %	TC, %
8	135	35	1468	1460	1456	1.64	0.085	3.24
9	125	30	1460	1452	....	1.50	0.086	3.32
8	15	40	1484	1476	1460	1.48	0.088	3.44
9	15	40	1468	1464	1444	1.46	0.074	3.22
8	75	35	1484	1476	1476	1.73	0.075	3.44
9	75	48	1460	1452	1440	1.54	0.094	3.32

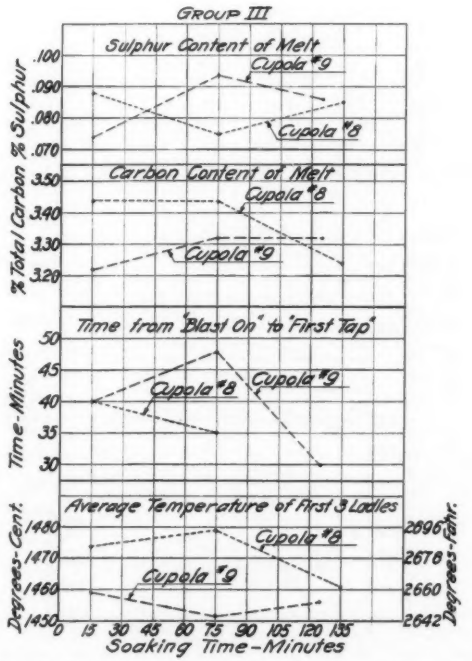

FIG. 3—THIRD GROUP OF TESTS. SEE DATA OF TABLE 4.

Tests of Group 4

13. Group 4 was a mixture of 75 per cent pig iron, 12 per cent cast scrap and 13 per cent steel, melted on a 58-in. bed in cupolas Nos. 5, 6 and 7. The blast pressure was 14 oz. and the phosphorus 0.70 per cent.

14. This last group contains more tests than any other group and shows greater inconsistency. The length of time from blast to first tap in this series is open to question because shop conditions demanded iron at a fixed time and, the basin of the cupola

Table 5

DATA OF TESTS OF GROUP 4

(75% pig, 12% scrap and 13% steel on 58-in. bed in cupolas Nos. 5, 6 and 7; blast pressure 14 oz.; phosphorus 0.7%)

Cupola No.	Soaking time, minutes.	Blast on to 1st tap, minutes.	—Temperature, degs. Cent.— 1st tap.	2nd tap.	3rd tap.	—Analysis of 1st ladle.— Si, %	S, %	TC, %	Remarks.
7	100	35	1468	1472	1476	1.38	.086	3.51	Extra steel*
5	95	33	1476	1480	1480	1.46	.084	3.51	Extra steel*
6	90	37	1476	1476	1472	1.54	.087	3.60	
6	20	35	1476	1476	1472	1.37	.098	3.57	
5	85	35	1480	1476	1468	1.51	.070	3.59	Special pig iron
6	20	35	1464	1476	1468	1.30	.095	3.61	
7	65	42	1460	1468	1472	1.46	.083	3.60	
5	15	33	1476	1472	1472	1.30	.096	3.58	
6	105	35	1484	1472	1468	1.39	.080	3.60	
7	120	35	1468	1468	1460	1.44	.081	3.60	

*Values marked extra steel or special pig iron were not plotted in Figs. 4 or 5 for sulphur or carbon content.

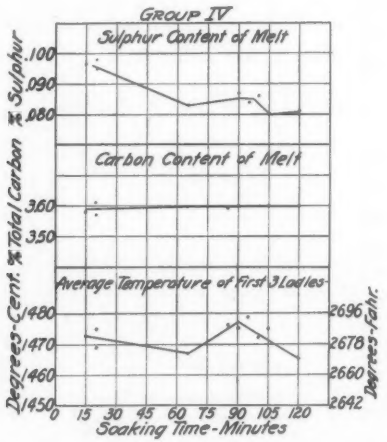

FIG. 4—FOURTH GROUP OF TESTS. SEE DATA OF TABLE 5.

holding more than a ladle, it is not certain that in all cases there was the same amount of iron melted when the cupola was tapped.

SUMMARY

15. In preparing a summary of all the groups, it was thought best to present the results graphically. Fig. 5 is a summation of all the tests. Values for cupola No. 9, Group 1; cupola No. 9, Group 2; average of results from cupolas Nos. 8 and 9, Group 3, and averages for cupolas Nos. 5, 6 and 7, were used in the graph of Fig. 5.

16. The figures obtained on a soaking time of 15 minutes were taken as a base and the difference between these and the values obtained for other soaking periods was plotted. When the soaking periods in a group were within ten minutes of each other in length, the results were averaged.

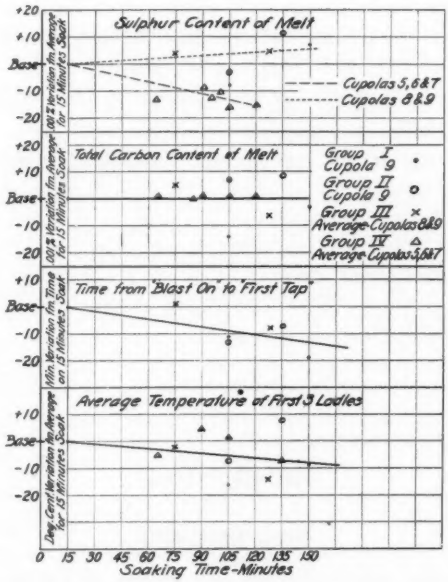
Sulphur Content of Melt
Cupolas 5,6&7
Cupolas 8&9
Total Carbon Content of Melt
Group I Cupola 9
Group II Cupola 9
Group III Average Cupolas 8&9
Group IV Average Cupolas 5,6&7
Time from "Blast On" to "First Tap"
Average Temperature of First 3 Ladles
Soaking Time-Minutes

FIG. 5—SUMMARY OF TEST RESULTS. FIGURES TAKEN ON A SOAKING TIME OF 15 MINUTES WERE TAKEN AS A BASE, AND THE DIFFERENCE BETWEEN THESE FIGURES AND THE VALUES OBTAINED FOR OTHER SOAKING PERIODS ARE PLOTTED ON ABOVE CURVES.

17. From Fig. 5 it can be seen that:

(a) The average temperature of the first three ladles in cupolas Nos. 8 and 9 tends to be lower for the longer soaking periods. In cupolas Nos. 5, 6 and 7 the results were more erratic, and around the 90-minute soaking period show high temperatures.

(b) The melting rate, as shown by the length of time required to melt a given amount of iron, is faster for the iron which has been soaked longest. Cupolas Nos. 5, 6 and 7 were not considered in this because of some doubt that a fixed amount of iron was melted before tapping in all cases.

(c) The total carbon content of the melt seems to be independent of the soaking time.

(d) The sulphur content of the melt in most cases increases with longer soaking. In cupolas Nos. 5, 6 and 7, where purite was used, the sulphur content is lower on longer soaking.

(e) Unmeasured factors—such as condition of bed, possible atmospheric changes, placing of charges, etc.—seem to have sufficient effect on the results to make the stating of exact laws, on the result to be obtained from any one soaking period under shop conditions, a very doubtful undertaking. All we can state is general tendencies.

18. On the whole, no especially beneficial results were obtained from soaking the charges. In fact, it seemed as though more heat was lost through the burning of the bed during the soaking time than was recovered in the heating of the charge. The coke burned with natural draft over a long period of time did not give as much heat to the charge as that coke which burned rapidly with the blast on the cupola.

DISCUSSION

ORAL DISCUSSION

MEMBER: Mr. Kiley, in discussing the paper by himself and his associate, said: "Use a 60-inch bed." I believe he was absolutely right as to the manner in which he is using his coke.

In the first place, the coke bed is used as the filler. The iron must

be tapped from the spout, as it is melted, in so many minutes from the time the blast goes on. For instance, if the iron is soaked for two hours, it is naturally destroying the coke bed. The result is that he must keep his coke bed high enough to make up for the coke that is burned out. On that basis, Mr. Kiley is absolutely right.

If the iron is soaked too long at the start, the coke bed is being destroyed. The result is that average charges must be larger to replenish what has been destroyed in the soaking. Then, too, a considerable amount of sulphur will be take up.

I have seen a cupola in which two sets of tuyeres were used in the ordinary way, and then eight rows of tuyeres about two inches in diameter. It was claimed that the iron was being preheated, but that is not my way of looking at it. All that those operators were doing was to burn out their charge of coke before it got down to the bed to replenish the bed. If the iron is not held up to the proper point in the bed, everyone knows that the metal is oxidized.

Someone has sated in this meeting that one-half the amount of coke mentioned by Mr. Kiley can be run, and I believe that he is right. However, that will depend to a great extent upon where the tuyeres are located. One man has his tuyeres down low and can run with a small amount of bed; but if he has his tuyeres high, it requires more coke to hold the iron up where it belongs.

J. M. SAMPSON:[1] I have been curious as to just what line of reasoning led the authors of this paper to think there would be any benefit from soaking.

W. H. SPENCER: The literature in general—some of it published in books, some in pamphlets—refers to the benefit of soaking. I have not given any quotations because I did not want to make this point controversial, but undoubtedly foundrymen have seen the statement that all cupolas should be filled up and soaked if good hot iron is desired.

N. A. MOORE:[2] Mr. Spencer, did you put all the charges in the cupola before estimating the soaking time?

W. H. SPENCER: The soaking time was taken from the time the first charge was put in, but all the charges were put in as rapidly as possible after the first one. The time was taken from the beginning of the first charge on the bed, but the rest were put in immediately afterward. In other words, the cupola was soaked full, not with just one charge.

N. A. MOORE: There might be considerable difference if the soaking time was taken from the time the cupola was charged; for example, if one charge requires 15 miutes and the other one hour.

W. H. SPENCER: The charges all were in within 15 minutes from the time of placing the first charge.

M. J. GREGORY:[3] In connection with this soaking period, I believe some other factors should be brought out, such as the type of castings made

[1]Foundry Engineer, General Electric Co., Schenectady, N. Y.
[2]Metallurgist, Piston Ring Co., Muskegon, Mich.
[3]Factory Manager, Caterpillar Tractor Co., Peoria, Ill.

and the type of scrap used. We all think of the automobile trade as requiring rather light castings. It is quite common, for instance, to take cylinder blocks out of the ladle almost before the cupola is full, which proves that hot iron can be obtained without soaking it for two hours. Mr. Kiley's problem relates to heavy castings, for which he has to soak the iron a little longer to get it hot. I believe that is Mr. Kiley's problem.

FRITZ W. MEYER:[4] In the discussion about the height of the coke bed, one most important factor was left out, namely, the amount of air entering the cupola. If we start with an extreme excess of air, we will soon oxidize the iron on account of the bed being burned low.

The height of the bed above the tuyeres is not the most important factor. I believe that the most important factor is the regulation between the weight of coke charges and the air supplied in such a way that the bed is kept at the same height at all times.

In other words, the use of a certain amount of air per square inch of the melting zone area is entirely wrong. If the weight of the coke charges is decreased, the amount of combustion air must be decreased accordingly. On the other hand, if the amount of the coke charges is increased, the air volume also must be increased.

The supply of oxygen should be regulated in such a way that the proper amount is supplied for each weight unit of coke. The amount of oxygen, for instance, depends upon the percentage of carbon in the coke. By doing this, it will be possible to keep the height of the bed at a constant level.

I know that we all have made (and still make) the mistake of not running with constant air supply according to the amount of coke burned in a given time. Some of us lower the melting rate by cutting down the air; then, if we want to increase the melting rate, we speed up the blower or fan.

By doing this, the top level of the coke bed may vary all the way from 10 to 60 inches above the tuyeres. In the case of attempting to increase the melting rate by means of supplying an excess of air, booster coke charges are added in order to build up the height of the bed, with the result that the height of the melting zone will jump all the way from close to the tuyeres to high up in the stack.

The only proper way to figure the proper air volume (if no devices are available to weigh the amount of oxygen) is to take the off-hand formula, *pounds of coke burned per minute* X *145 or 150 cubic feet of air.* Here the argument might come in with regard to the difference in the weight of air in winter and in summer. However, if we go on a basis of approximately 145 cubic feet of air per pound of coke burned in the time unit in winter time, and add approximately ten per cent to this volume for summer time, we are acting properly and will keep the top of our bed at a constant level for all heats.

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[4]Consulting Engineer, Rockford, Ill.

Contribution to the Study of the Influence of Phosphorus on the Iron*

By J. Dessent† and M. Kagan,** Liege, Belgium

1. The influence of all the elements, especially of phosphorus, on the properties of iron, has been the object of extensive researches. The results obtained vary and often have resulted in contradictory conclusions. Therefore, it has seemed logical to us to review the different stages of this research, summarizing the conclusions which can be considered as definite and unquestionable and bringing up some problems which demand solutions.

Phosphorus and Iron

2. Phosphorus has a great affinity for iron. In the liquid state, it dissolves in all proportions. The equilibrium diagram by Haughton (Fig. 1) again proves the existence of two definite compositions: Fe_3P and Fe_2P, the first with 15.58 per cent phosphorus, the second with 21.68 per cent phosphorus. Only the first one (Fe_3P) is of practical interest.

3. We can state that, at solidification, iron can dissolve up to 2.8 per cent phosphorus.[1] Between 2.8 per cent and 10.2 per cent, the mass solidifies in the form of primary crystals of solid solution (at 2.8 per cent) surrounded by the eutectic solid solution of Fe_3P (called "steadite" by Sauveur). Between 10.2 per cent and 15.6 per cent, the mixture consists of Fe_3P and of steadite. The steadite is a hard component (5.5 on the Mohr scale) and brittle.

4. The solubility of phosphorus in the solid iron, which is 2.8 per cent at solidification, drops down to 1 per cent at 700 degs.

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* Exchange paper submitted on behalf of the Belgian Technical Foundry Association.

† Metallurgical Engineer, Director of Foundries, Bressoux S. A.

** Civil Engineer of Mines, Assistant Lecturer in Metallurgy, The University of Liege.

[1] All the graphs published at an earlier date give the maximum solubility of phosphorus in the iron 1.7%. Recent results of research have given Haughton (Journal Iron and Steel Institute 1927, pp. 115 and 417) and Benedicks opinion that this limit is 2.8%.

Note: This paper was presented and discussed before one of the gray iron sessions at the 1931 convention of the American Foundrymen's Association.

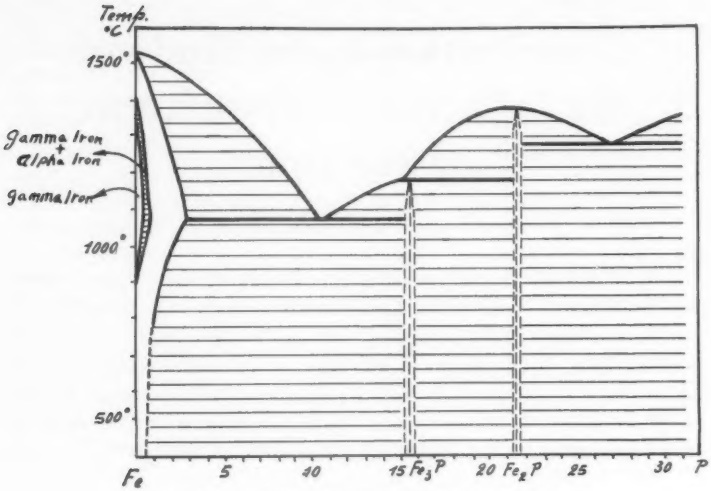

FIG. 1—IRON-PHOSPHORUS EQUILIBRIUM (ACCORDING TO HAUGHTON).

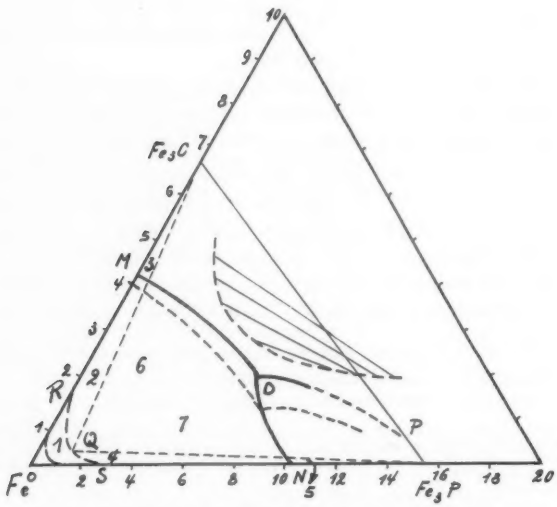

FIG. 2—TERNARY IRON-PHOSPHORUS DIAGRAM (ACCORDING TO GOEBENS).

Cent. (1292 degs Fahr.), and from then on decreases following the law, which is an essential function of the speed of cooling. The transformation of *alpha* iron into *gamma* iron, is marked by a little region located between 900 and 1400 degs. Cent. (1652 and 2552 degs. Fahr.). A second very narrow region follows and constitutes a region of two phases, *alpha* and *gamma*, the phase *alpha* being in all points identical with phase *delta*.

5. With the percentage of phosphorus higher than 0.5 per cent, it does not have the appearance of phase *gamma*. If large crystals carrying a phosphorus content higher than 0.5 per cent have been formed at high temperatures, they may be unchanged, depending on the cooling rate.

6. The diagram of Fig. 1 explains the coarse grain structure caused by phosphorus, at least when it is higher than 0.5 per cent. This remains true for lower contents because of local enrichments due to segregation.

THE TERNARY SYSTEM IRON—PHOSPHORUS AND CARBON

7. The ternary equilibrium diagram has been studied by a number of investigators such as Stead, Wüst, Goerens and Dobbelstein, and Vogel. The liquidus of the diagram (Fig. 2) can be character by the three curves of binary eutectic, these being shown in Fig. 2 as *MO*, *PO* and *NO* converging at the triple eutectic *O*. The solidus shows the system of the triple eutectic Fe_3 C.Q. Fe_3P, the two binary eutectics Fe_3C.Q.R. and Fe_3P.Q.S. and the complete solubility Q.R.S.Fe.

8. For the principal regions of the diagram, the solidification can be systematized in the following way:

(a) Deposition of *alpha* iron or solid solution of Fe_3C and Fe_3P in the *gamma* iron.

(b) *Alpha* iron with binary eutectic *alpha*—Fe_3C.

(c) Fe_3C with binary eutectic *alpha*—Fe_3C.

(d) *Alpha* iron with binary eutectic *alpha*—Fe_3P.

(e) Fe_3P with binary eutectic *alpha*—Fe_3P.

(f) *Alpha* iron with binary eutectic *alpha*—Fe_3P, with ternary eutectic *alpha*—Fe_3C—Fe_3P.

(g) *Alpha* iron with binary eutectic *alpha*—Fe_3P, with ternary eutectic *alpha*—Fe_3C—Fe_3P.

9. Among these combinations we have to consider especially those of region 1, (1, Fig. 2), which is the region of steel, and those of regions 2 and 6 which are the regions of industrial cast iron (2 with low phosphorus contents and 6 with high phosphorus contents).

10. Before examining what happens during the cooling in these different regions, there should also be mentioned the presence in the liquid state of a gap in solubility, limits of which are not well marked (the dotted curves on the diagram of Fig. 2 correspond to an isotherm of the empty space established by Goerens). As a result, for certain contents of carbon and phosphorus there is in the liquid stage a separation into two different compositions, the one rich in phosphorus and low in carbon, the other rich in carbon and low in phosphorus.

11. We now come to the subject of the influence of phosphorus on the total carbon content of cast iron.

TRANSFORMATION IN THE SOLID STAGE

Region of Steel.

12. In a pure hypo-eutectic iron-carbon alloy the transformation of austenite to ferrite and pearlite always taken between 700 and 900 degs Cent. (1292 and 1652 degs. Fahr.), and a zone of two phases—*alpha* and *gamma*—exists between the limits so defined by temperature. In the system Fe-P a zone of two phases exists between 900 and 1400 degs. Cent. (1652 and 2552 degs. Fahr.). In the ternary system this zone of two phases could likewise exist, so that in the presence of carbon and phosphorus the two phases could coexist not only as in the case of the iron carbon system up to 900 degs. Cent. (1652 degs. Fahr.) maximum but likewise up to temperatures much higher than that.

13. In case of annealing of steel, the *gamma* phase is never produced alone but will always consist of crystals of phosphoritic ferrite which will grow by coalescence and will remain the same during the cooling. This is the orgin of the ferrite bands which are characteristic of the structure of steels which contain phosphorus.

Region of Iron.

14. The cast iron mixtures (from 2.7 to 3.3 per cent total carbon) exist in regions 2 and 6 (Fig. 2), in region 2 for the mixtrues with less than 0.6 per cent phosphorus, and in region 6 for mixtures with more than 0.6 per cent phosphorus. First let us consider the case of the metastable equilibrium of the cementite in the diagram Fe-C.

15. In region 2 we have, successively, the following two depositions:

(a) Solid solution (Fe *gamma*—Fe_3C—Fe_3P).

(b) Eutectic binary solid solution, Fe_3C.

16. In region 6 we have the three depositions as follows:

(a) Solid solution (Fe *gamma*—Fe_3C—Fe_3P).

(b) Eutectic binary solid solution, Fe_3C.

(c) Eutectic ternary solid solution, Fe_3C—Fe_3P.

17. After the transformations, the mixtures of region 2 consist of cementite and crystals of phosphoritic pearlite, without special constituents, all the phosphorus forming a solid solution in the ferrite and pearlite, which fact corresponds with observations made. The mixture of region 6 will, in contrast and as mentioned before, leave the appearance of a special constituent after transformation, the constituents *A* and *B* being built up as in the preceding case.

18. For constituent *C*, let us look at its real composition. It contains 2 per cent carbon and averages 7 per cent phosphorus, which is the same as 30 per cent Fe_3C, 45 per cent, Fe_3P and 25 per cent Fe. This 25 per cent Fe has dissolved some percentages of phosphorus and forms the phosphoritic ferrite which, with certain percentages of Fe_3C (86.5 per cent Fe and 13.5 per cent Fe_3C) forms the pearlite.

19. The phosphorus eutectic, as it appears to us, consists essentially of Fe_3P with small portions of pearlite and cementite (Fig. 3). According to the speed of cooling, the cementite and pearlite coalesce in greater or smaller quantities with crystals of the same nature already deposited.

20. Let us look for a moment at what happens in the case of gray iron. Gutowsky, Bolton and MacKenzie maintain that in this case we find only a binary eutectic due to the decomposition

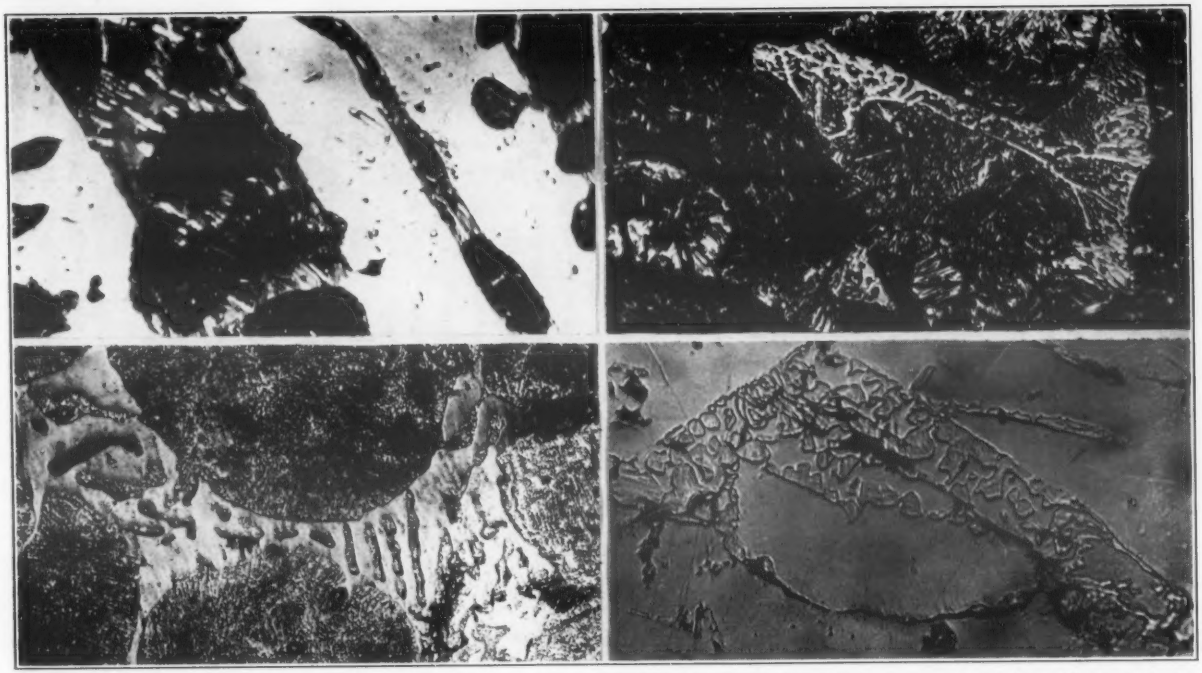

FIG. 3, 4, 5, 6—PHOTOMICROGRAPHS OF PHOSPHIDE EUTECTIC IN WHITE IRON (FIG. 3, UPPER LEFT), AND IN GRAY IRON (FIGS. 4, 5, 6). FIG. 3: CEMENTITE SHOWS WHITE, PEARLITE BLACK AND THE Fe_3P GRAY. ETCHED ACCORDING TO KÜNKELE. FIG. 4 (UPPER RIGHT): THE THREE CONSTITUENTS ARE SAME AS IN FIG. 3. FIG. 5 (LOWER LEFT): SHOWING TWO CONSTITUENTS, PHOSPHIDE AND PEARLITE. ALL FIGURES X900.

Table 1

Results of Experiments by Wüst on Effect of Phosphorus on Solidification Point of Gray Iron

Phosphorus per cent.	Temperature of Solidification Degs. Cent.	Temperature of Solidification Degs. Fahr.	Phosphorus, per cent.	Temperature of Solidification Degs. Cent.	Temperature of Solidification Degs. Fahr.
0.02	1145	2093	4.61	1005	1841
0.07	1130	2066	5.80	960	1760
0.28	1130	2066	6.55	1000	1832
0.88	1110	2012	8.17	1050	1922
2.34	1070	1958	11.72	1060	1940
3.27	1040	1904	13.90	1105	2021
3.94	1020	1868	21.60	1340	2444

of Fe_3C. Others, like Schwarz, consider this eutectic as ternary. It is this last hypothesis, extremely simple to explain on the ternary diagram (Fig. 2), which we support. We admit, indeed, that the diagram Fe-C is double; therefore, the lines of the ternary diagram Fe-C-P have to be doubled because of the change from the metastability of cementite to the stability of graphite.

21. Consequently, all we have said about white iron can be applied to gray iron, replacing the cementite by the products of its decomposition—ferrite and graphite. Up to about 0.6 per cent (region 2, Fig. 2, of binary eutectic alone) we will not have separate components; the products of decomposition of the solid solu-

Table 2

Coulability Tests of Gray Iron with Remy Test Bar

Melt No.	T.C.	Si.	Mn.	S.	P.	Length of Flow Indicated by No. of Marks on Test Bar.
1	3.25	0.67	0.49	0.089	0.05	6
2	3.63	0.75	0.48	0.091	0.21	3
3	3.60	0.72	0.47	0.088	0.36	3
4	3.50	0.75	0.46	0.107	0.60	10
5	3.38	0.70	0.45	0.106	0.80	12
6	3.34	0.67	0.45	0.098	0.98	6
7	3.30	0.72	0.45	0.104	1.44	13.5
8	3.07	2.38	0.74	0.107	0.24	..
9	3.10	2.29	0.91	0.108	0.64	7
10	2.80	2.31	1.11	0.125	1.26	10
11	2.96	2.43	0.85	0.110	1.38	11
12	2.96	2.54	0.64	0.112	....	12
13	2.86	2.52	0.62	0.100	1.62	14

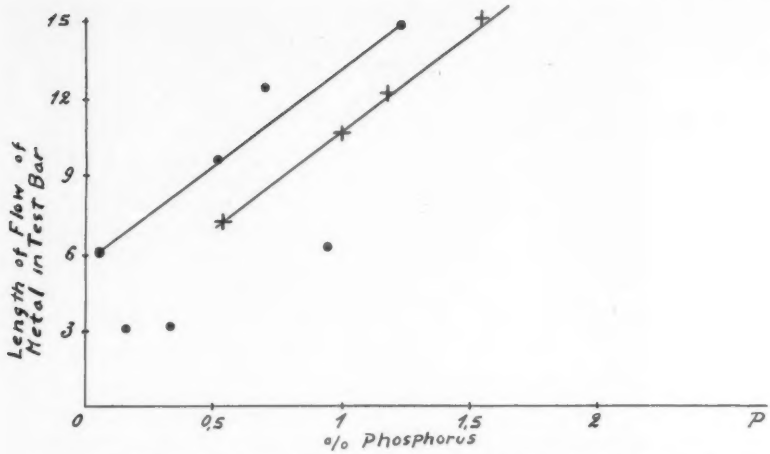

FIG. 7—RESULTS OF TESTS SHOWING FLUIDITY INCREASE WITH INCREASE OF PHOSPHORUS CONTENT.

Table 3

RESULTS OF EXPERIMENTS BY STEAD ON EFFECT OF CARBON ON SATURATED MIXTURE OF PHOSPHORUS IN GRAY IRON

Per cent of Carbon.	Per cent of Free Phosphorus.	Per cent of Phosphorus in Solution.	Phosphorus, total per cent.
.....	....	1.75	1.75
0.125	0.18	1.37	1.55
0.180	0.59	1.18	1.77
0.70	1.00	0.75	1.75
0.80	1.06	0.70	1.76
1.40	1.16	0.60	1.76
2.00	1.18	0.55	1.73
3.50	1.40	0.31	1.71

Table 4

RESULTS OF EXPERIMENTS BY WÜST ON EFFECT OF PHOSPHORUS ON TOTAL CARBON CONTENT OF GRAY IRON

Phosphorus, per cent.	Total Carbon, per cent.	Phosphorus, per cent.	Total Carbon, per cent.
0.02	4.27	5.80	2.25
0.28	4.04	6.55	2.14
0.83	3.98	8.17	1.89
2.34	3.34	11.72	1.36
3.27	3.29	13.90	0.80
4.61	2.41	21.56	0.28

tion and of the binary eutectic can give us only phosphoritic ferrite, pearlite (with phosphoritic ferrite), and graphite. Above this content there is free Fe_3P left, which will be punctuated with ferrite (or cementite) and with pearlite (the graphite in extremely small quantities cannot be discerned).

22. The speed of cooling, by affecting the coalescence, can cause the disappearance of one of the constituents and sometimes even two, so that very often the phosphorus eutectic of the melts will have a binary appearance or may even appear to be Fe_3P alone.[2] The three photomicrographs (Figs. 4, 5 and 6) show three, two or one constituents which can occur in the phosphorus eutectic in the gray iron, as discussed below.

Points of Solidification and of Fusion

23. The binary eutectic or ternary eutectic are caused by the lowering of the solidification point. Wüst has determined this lowering of the solidification point with increasing contents of phosphorus. These results are shown in Table 1.

24. This lowering of the solidification point leads to a much greater fluidity of the metal, and this quality is most interesting from the practical point of view. As it is difficult to determine the viscosity practically, we have conducted some tests of coulability with the test bar of Remy (modification of the test bar suggested by Saito and Hayaske). The results are given in Table 2.

25. The melts Nos. 1 to 7, in Table 2, are the mottled irons, melted in a crucible and poured at temperatures averaging 1200 degs. Cent. (2192 degs. Fahr). The melts Nos. 8 to 13, are pearlitic irons from the cupola poured from 1280 to 1300 degs. Cent. (2336 to 2372 degs. Fahr.), the ferrophosphorus having been added in the liquid state to the ladle. Fig. 7 gives the results of these tests.

Influence of Phosphorus on Total Carbon Content

26. A resumé of the results of a number of research men shows that increasing phosphorus content has the effect of lowering the carbon content. Stead has added increasing quantities of carbon to a saturated mixture of phosphorus and has observed

[2] Kunkele, who has made a metallographic study of this question, has arrived at the conclusion that the phosphorus eutectic of gray iron is composed of phosphorus, pearlite and cementite (the latter however may break down or not); in certain cases where cementite is not found (fact explained before), this eutectic is called "pseudo-binary."

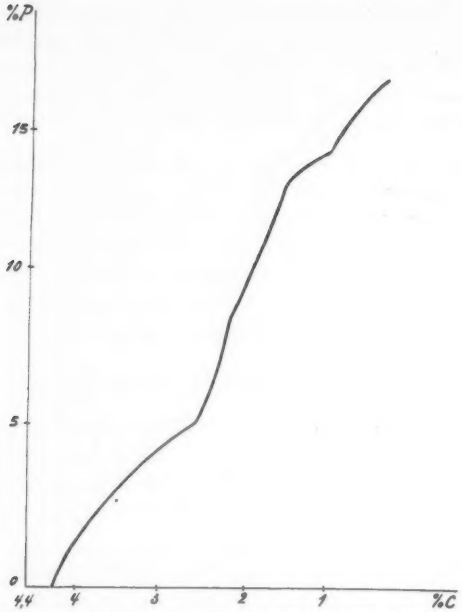

FIG. 8—RESULTS OF INCREASING PHOSPHORUS ON CARBON CONTENT (ACCORDING TO BOLTON).

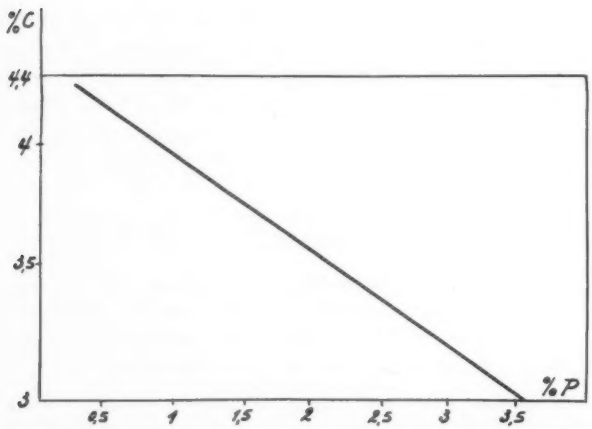

FIG. 9—RESULTS OF INCREASING PHOSPHORUS ON CARBON CONTENT OF CAST IRON WITH ONE PER CENT SILICON (ACCORDING TO MACKENZIE).

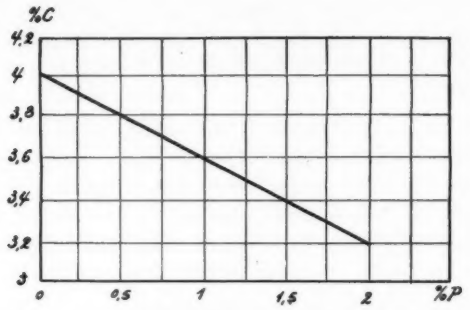

FIG. 10—RESULTS OF INCREASING PHOSPHORUS CONTENT ON CARBON CONTENT OF CAST IRON WITH TWO PER CENT SILICON (ACCORDING TO MACKENZIE).

that the carbon has driven out the phosphorus. The results are given in Table 3.

27. Wüst has conducted similar experiments, and his results are given in Table 4; the same results are shown graphically by Bolton in Fig. 8.

28. MacKenzie has made a series of tests with commercial pig irons from different districts and from different furnaces. His results are represented in the diagrams of Figs. 9 and 10, that of Fig. 9 representing a mixture having 1 per cent silicon, and that

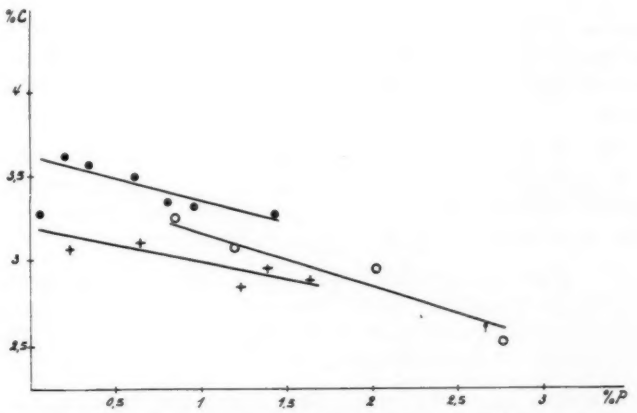

FIG. 11—RESULTS OF INCREASING PHOSPHORUS ON CARBON CONTENT OF CAST IRON.

of Fig. 10 representing a mixture of 2 per cent silicon. The result of these tests conforms to the conclusion of Stead and Wüst, that the high contents of phosphorus have a tendency to lower the content of carbon.[3]

29. On air furnace melting, the results found are very irregular, undoubtedly due to the variations of operation, because (as it will be shown later) temperature has a primary influence on this phenomenon. The mutual rejection of phosphorus and carbon in the liquid melt can be explained very easily by the lack of solubility in the liquid state, as pointed out clearly by Goerens.

30. For certain contents of phosphorus and carbon, a separation took place in the ladle into two liquid layers whose compositions followed the limits of lack of solubility, the one rich in carbon and poor in phosphorus, the other rich in phosphorus and poor in carbon. This phenomenon, of course, will be essentially a function of the temperature—it will be more pronounced, the lower the temperature. This explains the results causing conclusions by certain research men which differ from the conclusions of Stead and Wüst.

INFLUENCE OF PHOSPHORUS ON COMBINED CARBON AND GRAPHITE

31. Nearly all the research performed has resulted in the definite conclusion that, up to the content of 2.5 per cent phosphorus, the phosphorus has no effect on the speed of precipitation nor on the quantity of graphite precipitated. A lower content seems to favor the precipitation (according to Stead and Wüst) for the mixtures low in silicon (0.5 per cent). It is only from 2.5 per cent phosphorus on that we find a favorable influence of phosphorus.

32. At a content of 5 per cent phosphorus, this influence is at its maximum; 60 per cent of the total carbon is present as graphitic carbon. For a content of 0.9 per cent silicon, the increase of graphite begins at 3 per cent phosphorus.

33. Wüst also has found that, in phosphorus containing irons, the graphite has a tendency to form nests. It seems also that the presence of high contents of both phosphorus and silicon favors the formation of mossy graphite.

[3] The analyses of cast irons from different sources with varying contents of phosphorus, made by us and shown on the diagram of Fig. 11, again confirm these conclusions. Practically, this tendency appears irregularly because of the variations in cooling temperatures.

Table 5

RESULTS OF EXPERIMENTS BY HATFIELD ON EFFECT OF PHOSPHORUS ON TOTAL CARBON CONTENT

Phosphorus, per cent.	Total Carbon, per cent.	Si.	S.	Mn.
0.046	2.90	0.75	0.038	0.25
0.100	2.90	0.77	0.038	0.25
0.145	2.90	0.71	0.041	0.25
0.229	2.89	0.78	0.041	0.25
0.287	2.87	0.72	0.038	0.26
0.600	2.84	0.77	0.039	0.28
0.830	2.83	0.76	0.030	0.25

34. Kerpely, in accordance with Stead, finds that in the lower contents the phosphorus does not influence the content of combined carbon. With a mixture having 1 per cent phosphorus, he has succeeded in getting a Brinell hardness of 200 and a perfect machinability.

35. The results of Hatfield, who added an increasing quantity of phosphorus to a white iron, are completely conclusive in this point of view. The content of phosphorus increased from 0.046 to 0.83 per cent. The contents of silicon, manganese and sulphur remain the same. Hatfield has not mentioned the presence of primary graphite and the mixture retained always the white structure, having always a Brinell hardness averaging 400. His results are given in Table 5.

36. At any rate, we must note that unanimity does not exist in regard to this question. The tests of Hamasumi, on the contrary, seem to show us that with the contents of 1 to 3 per cent

Table 6

RESULTS OF EXPERIMENTS BY DENNISON ON EFFECT OF PHOSPHORUS ON CARBON IN GRAY IRON

Phosphorus, per cent.	Total Carbon, per cent.	Combined Carbon, per cent.	Graph. Carbon, per cent.	Si.	S.	Mn.
0.79	3.09	0.31	2.78	2.02	0.071	0.59
0.86	3.07	0.28	2.79	2.00	0.072	0.57
0.92	3.05	0.25	2.80	2.00	0.069	0.56
0.99	3.02	0.21	2.81	1.96	0.072	0.54
1.04	3.00	0.19	2.81	1.98	0.070	0.56
1.12	2.97	0.17	2.80	1.99	0.070	0.54
1.20	2.99	0.15	2.85	2.04	0.060	0.55

Table 7

RESULTS OF EXPERIMENT BY LEDEBUR ON PER CENT OF PHOSPHORUS IN SEGREGATED PARTICLES

Contents.	Analysis of Mixture, per cent.	Analysis of Chilled Drops, per cent.
T. C.	3.4	3.7
Si.	2.04	1.63
Mn.	0.43	0.42
P.	0.44	1.98
S.	0.08	0.05
Cu.	0.03	0.10

phosphorus, the phosphorus favors rather the decomposition of the cementite. From 3 per cent phosphorus on, we find rather an increase in combined carbon.

37. Dennison is of the same opinion as Hamasumi. He finds that anything that lowers the point of solidification favors the formation of graphite by decreasing the quantity of combined carbon. The results of Dennison's tests are given in Table 6.

38. These results show the decrease of combined carbon successively according to the increase of phosphorus content. With regard to the graphitic carbon, this remains unchanged, a phenomenon probably due to the decrease of the total carbon under the influence of phosphorus.

PHOSPHORUS AND SEGREGATION

39. The phosphorus, lowering the eutectic temperature and forming an eutectic which remains fluid a long while, should favor segregation. The substances which form a double system with the Fe (especially phosphorus) are the ones which separate themselves. Enrichment takes place in the part which remains liquid the longest time (mother fluid).

40. The combination Fe-P-C, being of eutectic nature, is present in the part which solidifies last. Between 953 degs. Cent. (1747 degs. Fahr.) and the complete solidification of the mass, there is an interval sufficient to permit a separation. Also, the chilled drops (according to Geiger) which are found on the inside of shrink holes are due to segregation under pressure. The outside, while solidifying, causes a pressure on the inside liquid and makes a pasty mass of small drops squeeze through.

41. Ledebur has made some analyses of these chilled drops and has found (Table 7) that these drops show a very marked increase in phosphorus.

PHOSPHORUS AND SHRINKAGE

42. As phosphorus has no influence on the precipitation of graphite, it has no influence on the shrinkage of iron. Keep, on the contrary, found that phosphorus has a tendency to decrease the shrinkage.

PHOSPHORUS AND THE REPEATED HEATING OF THE IRON

43. The experiments of Charpentier have established the fact that phosphorus decreases growth and favors uniform expansion. The metallographic experiments of Pisek and of Bosart confirm the conclusions of Charpentier. They have established the facts that:

(a) The mixed crystals of Fe rich in phosphorus are difficultly oxidizable, which results in a comparatively slow increase in volume.

(b) The mixed crystals form a continuous network in the metal, which prevents the penetration of gases.

(c) During the decomposition, the phosphorus eutectic surrounds the ferrite crystals and protects them from oxidation.

(d) The eutectic which is decomposed fills the cracks which are formed in the graphite.

44. The experiments of Kennedy and Oswald on the same phenomenon corroborate the previous conclusion, that the mixtures having increased phosphorus content grow more slowly than the ones with low phosphorus content.

PHOSPHORUS AND ELECTRICAL CONDUCTIVITY

45. No definite results are available on the influence of phosphorus on the electrical conductivity of iron.

46. In order to establish the above, it is compared with steel. It was found that for a steel with 0.11 per cent carbon, phosphorus from 0 to 1.2 per cent increased the specific resistance from 16 up to 30 microhms—this means that each per cent of phosphorus increased the resistance from 11.6 microhms.

Table 8

ANALYSIS OF IRONS USED IN CORROSION EXPERIMENT OF TABLE 9

Sample.	Total Carbon, per cent.	Si.	Mn.	S.	P.	Observations.
FP	3.23	3.50	0.56	0.064	0.84	Gray fracture.
FP1	3.11	3.71	0.56	0.062	1.18	Gray fracture.
FP2	3.70	3.45	0.56	0.068	2.04	Gray fracture.
FP3	2.51	3.13	0.56	0.047	2.86	Gray fracture.
FP4	0.52	3.24	0.56	0.045	8.50	White fracture.

47. The experiments of Pinsl have demonstrated that the influence of phosphorus is not so great. In the presence of silicon and graphite, the phosphorus rather lowers the resistance. For explanation he gives the fact that in steel the phosphorus is in solid solution like mixed crystals, while in cast iron it is like an eutectic.

48. The eutectic seems to increase the electrical resistance less than the phosphorus in solid solutions of phosphorus in Fe. Furthermore, with high phosphorus content we find the eutectic parts surrounded by a network of graphite flakes which decrease the electrical resistance. We can say that in the cast iron the phosphorus has a direct and an indirect influence.

PHOSPHORUS AND CORROSION

49. According to Bolton, the phosphorus-containing parts are very resistant to corrosive agents. The order of their sensitiveness against attack by corrosive agents is: Sulphur, ferrite, pearlite, cementite, phosphorus eutectic and graphite.

50. We see that the phosphorus eutectic resists corrosive agents better than do the other constituents. We can suppose

Table 9

RESULTS OF EXPERIMENTS BY BOLTON ON CORROSION OF IRONS OF TABLE 8 BY VARIOUS ACIDS, SHOWING LOSS IN WEIGHT IN PERCENTAGE OF ORIGINAL WEIGHT

Sample.	HCl, 10%	HCl, 1/1	H_2SO_4, 1/1	HNO_3, 1/1	NaCl, 5%
FP	28.7	31.1	21.1	18.4	0.08
FP1	31.0	36.8	16.5	12.8	0.11
FP2	28.5	25.4	10.7	14.3	0.05
FP3	18.7	13.5	6.9	12.4	0.06
FP4	5.30	3.3	3.8	21.8	0.30

that in the high contents the phosphorus lowers the corrosiveness of the metal. Lower contents, on the contrary, have a harmful effect by causing an electrolytic action.

51. We have proceeded with some tests on cast irons high enough in phosphorus content as to verify this fact. The studies on this cast iron were on the irons given in Table 8.

52. The results of these tests are shown in Table 9 and Fig. 12. The experiments have been carried on with samples of similar form and of approximately the same weight. The figures of the table give the loss in weight in percentage of the original weight. The duration of the attack was 75 hours.

PHOSPHORUS AND PHYSICAL PROPERTIES

53. Several research men have thought that phosphorus would have a tendency to increase the strenggh of cast iron. It is the presence of a eutectic network in cast iron with high strength which explains this point of view. Dennison finds that, up to 0.8 to 1 per cent phosphorus, the phosphorus has no influence on the strength in tension.

54. By a series of tests with the iron superheated to 1650 degs. Cent. (3002 degs. Fahr.), Kerpely shows that a content of phosphorus from 0.7 per cent to 0.8 per cent shows the same resistance in tension as the ones with 0.3 per cent phosphorus. The result of these tests are given in the diagram of Fig. 13.

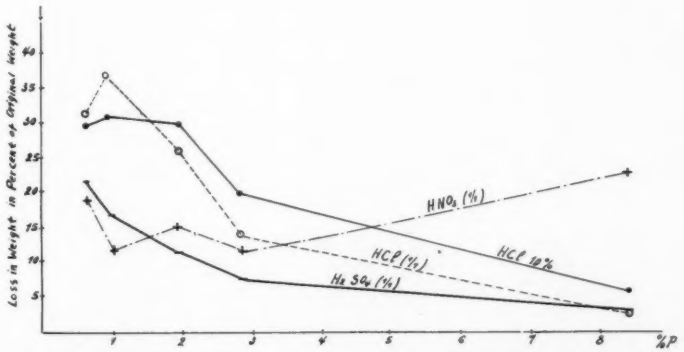

FIG. 12—RESULTS OF TESTS SHOWING DECREASING LOSS IN WEIGHT WITH INCREASING PHOSPHORUS CONTENT WHEN ATTACKED BY VARIOUS ACIDS.

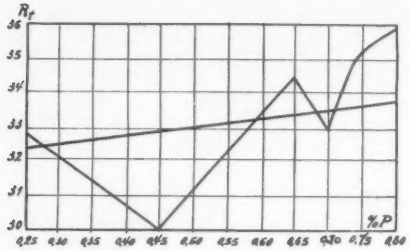

FIG. 13—EFFECT OF PHOSPHORUS CONTENT ON STRENGTH (ACCORDING TO KERPELY).

Table 10

RESULTS OF EXPERIMENTS BY KERPELY ON EFFECT OF PHOSPHORUS ON TENSILE STRENGTH

Phosphorus, per cent.	Tensile Strength, per Kg./mm.²	Total Carbon, per cent.	Combined Carbon, per cent.	Graph. Carbon, per cent.	Si.
0.026	23.15	3.10	0.75	2.33	1.78
0.123	25.99	2.94	0.75	2.22	1.66
0.222	28.82	3.03	0.85	2.18	1.75
0.308	31.50	2.87	0.80	2.07	1.77
0.504	27.88	3.00	0.90	2.10	1.74
0.670	23.47	3.00	0.85	2.15	1.57
1.806	23.44	2.85	0.63	2.22	1.68
2.775	19.53	2.85	0.75	2.10	1.81
3.050	17.65	2.71	0.79	1.92	1.63
4.173	17.48	2.88	0.88	1.95	1.57
5.095	14.35	2.95	0.85	2.10	1.63

Table 11

RESULTS OF EXPERIMENTS BY MACKENZIE ON EFFECT OF PHOSPHORUS ON MODULUS OF RUPTURE

No. of Tests.	Phosphorus, per cent.	Modulus of Rupture, per Kg./mm.²
66	0.31	34.2
66	0.67	30.3
25	1.16	30.3
23	1.95	24.7
6	3.15	22.2

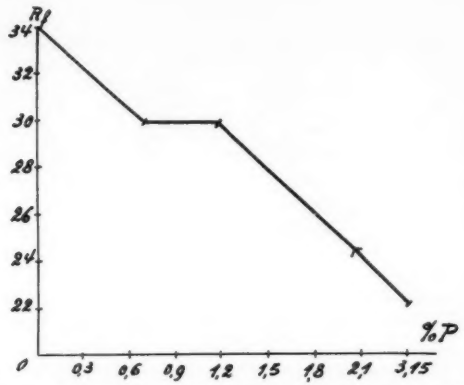

FIG. 14—EFFECT OF INCREASE OF PHOSPHORUS IN CAST IRON ON MODULUS OF RUPTURE (ACCORDING TO MACKENZIE).

55. Rudeloff finds also that *Rt*, or tensile strength, and *Rf*, or modulus of rupture in transverse test, are not influenced by the phosphorus content lower than 1 per cent. On the contrary, the main part of the tests made with cast iron of normal condition have proved that with increased contents of phosphorus the mechanical qualities are decreased.

56. The experiments of Wüst have shown that the maximum tensile strength and modulus of rupture are obtained with a content of 0.3 per cent phosphorus. The results of a series of experiments made by Kerpely are given in Table 10.

57. We see that here, also, the best results have been obtained by phosphorus contents of 0.3 per cent. Above 0.3 per cent phosphorus we find a strong decrease in the tensile strength.

58. For the resistance of deflection the same results were obtained. MacKenzie has found, in a great number of tests, the results given in Table 11.

Table 12

RESULTS OF EXPERIMENTS BY KEEP ON EFFECT OF PHOSPHORUS ON MODULUS OF RUPTURE

Phosphorus, per cent.....	0.5	1.0	1.5	2.0	2.5
	——Modulus of Rupture, in Kg./mm.²——				
Gray Iron.....	31.5	26.2	26.0	18.9	15.4
White Iron.....	13.6	12.6	13.8	9.7	8.4

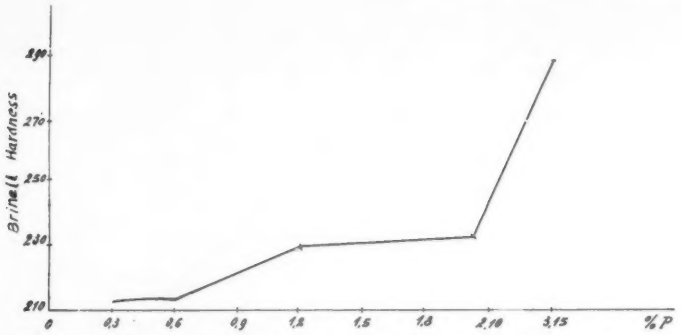

FIG. 15—EFFECT OF INCREASE OF PHOSPHORUS IN CAST IRON ON BRINELL HARDNESS (ACCORDING TO MACKENZIE).

59. The results represented by the diagram of Fig. 14 show clearly that with the increase in phosphorus content, the *Rf* (modulus of rupture) decreases, reaching its maximum at contents approaching 3 per cent phosphorus.

60. Keep added phosphorus to a hematite pig iron and found that phosphorus lowered the modulus of rupture (Table 12).

61. Wüst and Goerens, who have worked on the influence of phosphorus on shock resistance, found that when varying the contents of phosphorus from 0.1 per cent to 1.3 per cent the shock resistance was decreased 50 per cent. The compression resistance is, according to Dennisson, decreased at increased phosphorus contents, due to the decrease of combined carbon and the increase of phosphorus.

Hardness.

62. Due to the formation of the eutectic, the hardness of cast iron increases with increased content of phosphorus. The effect is double, due to the decrease of total carbon caused by the increase of phosphorus.

63. MacKenzie, in the tests mentioned, furthermore found that when varying the phosphorus content from 0.31 to 3.15, the Brinell hardness varies from 211 to 290. Results are shown in Fig. 15.[4]

64. The same result was obtained by Kerpely, as shown in Table 13.

[4] The cast FP4 (Table 8) shows a Brinell hardness of 451.

Table 13

RESULTS OF EXPERIMENT BY KERPELY ON EFFECT OF PHOSPHORUS ON BRINELL HARDNESS

Phosphorus, per cent.	Brinell Hardness.	Phosphorus, per cent.	Brinell Hardness.
0.026	175	1.806	203
0.123	189	2.775	216
0.222	193	3.090	227
0.308	213	4.173	230
0.500	195	5.025	226
0.670	202		

Deflection.

65. Regarding the deflection, the experiments of MacKenzie have shown that the test bars having the highest phosphorus content have more deflection at a given load than do those with lower contents of phosphorus. On the contrary, Wüst and Goerens found that phosphorus decreases the deflection.

PHOSPHORUS AND MALLEABLE IRON

Phosphorus and Carbon in Malleable Iron.

66. Very little knowledge exists about the influence of phosphorus on the carbon of annealed cast iron on the speed of precipitation and on the precipitated quantity. As a general rule, we think that phosphorus does not influence graphitization, and that it neither favors nor retards the decomposition of cementite. Phosphorus has no influence on the temperature at which this

Table 14

RESULTS OF EXPERIMENTS BY WÜST ON EFFECT OF PHOSPHORUS ON PER CENT OF TEMPER CARBON IN MALLEABLE IRON

Total Carbon, per cent.	Graph. Carbon, per cent.	Phosphorus, per cent.	Hours of Annealing.	Annealing Temperature Degs. Cent.	Annealing Temperature Degs. Fahr.	Temper Carbon, per cent.
3.72	0	0.50	3	1000	1832	0.32
3.72	0	0.50	3	1100	2012	2.30
3.99	0.01	0.42	3	1000	1832	0.40
3.99	0.01	0.42	3	1100	2012	1.56
3.91	0	0.33	3	1000	1832	0.31
3.91	0	0.33	3	1100	2012	2.48
3.28	0	0.23	3	1000	1832	0.53
3.28	0	0.23	3	1100	2012	1.07

Table 15

RESULTS OF EXPERIMENTS BY HATFIELD ON EFFECT OF PHOSPHORUS ON MECHANICAL PROPERTIES OF MALLEABLE IRON.

Phosphorus per cent	Yield Point		Tensile Strength		
	Tons per sq. in.	Lbs. per sq. in.	Tons per sq. in.	Lbs. per sq. in.	Per cent Elongation in 3 inches
0.045	15.31	34,294	23.79	53,289	6.5
0.100	16.17	36,221	22.64	50,713	5.0
0.145	16.59	37,161	22.04	49,369	4.5
0.229	17.53	39,267	21.78	48,787	3.5
0.287	17.65	39,536	22.37	50,108	4.0
0.600	20.16	45,158	20.86	46,726	2.5
0.830	18.44	41,305	19.24	43,097	2.0

decomposition takes place. These conclusions are based on experiments of oxidizing annealing by Wüst (Table 14).

67. Schwartz finds also, with regard to this question, that phosphorus is the only element which has no influence on graphitization. The small differences found by Wüst are rather due to other factors and appear for other elements.

PHOSPHORUS AND THE STRENGTH OF MALLEABLE IRON

68. According to Ledebur, the phosphorus content of the malleable iron need not be higher than 0.2 per cent to have a bad influence on the ductility and *Rt*, or tensile strength. Schwartz is of the same opinion about phosphorus contents from 0.05 per cent to 0.15 per cent.

Table 16

EFFECT OF PHOSPHORUS ON TENSILE STRENGTH AND ELONGATION OF MALLEABLE IRON.

Phosphorus, approx. per cent	Tensile Strength Kg./mm²	Elongation, per cent
0.0	42.1	1.9
0.3	40.2	1.9
0.6	32.9	0.9
0.9	34.3	0.8
1.2	28.0	0.8
1.5	23.0	0.6
1.8	16.8	0.3
2.1	13.5	0.3

69. Touceda has found that in the presence of small quantities of combined carbon in the annealed malleable iron, it takes a high amount of phosphorus to influence the mechanical properties—the samples with 0.325 per cent having a higher resistance than those with 0.25 per cent and 0.181 per cent, with the same contents of the other elements. Even 0.388 per cent phosphorus does not give a more brittle casting and does not decrease the tensile strength; neither does it influence the grain size.

70. The experiments of Hatfield with a series of test bars having an increasing phosphorus content (Table 15) show, in accordance with Ledebur, that from 0.25 per cent phosphorus on, the mechanical properties of malleable iron start to decrease, and that it starts to show a crystalline formation which entirely changes the fracture of the iron.

71. Finally, experiments conducted in Russia not only confirm the results obtained by Touceda, but are even more convincing. The phosphorus content was changed from 0.14 per cent to about 0.70 per cent, with a silicon content of 0.45 per cent. The higher contents of phosphorus have given better results than the lower contents. There are the following results:

Tensile strength = 59,136 lbs. per sq. in., against 50,400.
Per Cent reduction of area = 2.14, against 1.82 (on 50 mm.).
Hardness (3000/10/30) 179 against 179.

72. We have experimented with pearlitic malleable iron in the crucible with the phosphorus contents increasing from 0 up to 2.1 per cent, and have obtained the results given in Table 16.

73. One finds a regular drop of tensile strength and the elongation is effected from 0.3 per cent on.

DISCUSSION

ORAL DISCUSSION

J. T. MACKENZIE:[1] The author quotes from my paper of 1925,* in which I tentatively showed that the phosphorus appeared to increase the deflection at a given point on the load deflection program. I want to get

[1] Metallurgist, American Cast Iron Pipe Co., Birmingham, Ala.

* MacKenzie, J. T., *The Influence of Phosphorus on the Total Carbon Content of Cast Iron*, TRANSACTIONS A. F. A. (1925), vol. 33, p. 445.

on record the fact that I wrote a paper* the next year, 1926, which conclusively disproved my tentative conclusion of 1925.

H. R. CLARKE:[2] There is one question about phosphorus that I do not believe has ever been quite cleared up. I find foundrymen in general are of the opinion that it greatly reduces the transverse strength. I think the reason for this is that they have misinterpreted the results of data that have been brought forth.

This paper gives the foundryman reliable information about most of the physical qualities in his iron which he might expect by increasing or reducing phosphorus in his cupola mix. However, this paper and, so far as I know, no other investigation has yet answered the question, "Will

* MacKenzie, J. T., *The Influence of Phosphorus on Cast Iron*, TRANSACTIONS A. F. A. (1926), vol. 34, p. 986.

[2] Metallurgist, Sloss-Sheffield Steel & Iron Co., Birmingham, Ala.

Table 17

HIGH-PHOSPHORUS SERIES

Set No.	Ultimate Strength, lbs.	Drop Test.	Si	S	Mn	P	TC
154	1820	11.0	1.91	0.064	0.59	0.08	3.86
159	1960	11.5	1.75	0.070	0.54	0.09	3.80
238	2490	15.0	1.65	0.070	0.43	0.17	3.54
239	2560	15.0	1.62	0.072	0.40	0.17	3.51
244	1800	11.5	1.78	0.072	0.47	0.18	3.69
243	2230	15.0	1.65	0.071	0.41	0.18	3.64
237	1700	11.0	1.82	0.058	0.46	0.19	3.73
235	1760	11.0	1.93	0.057	0.50	0.20	3.78
254	2070	13.0	1.82	0.076	0.36	0.20	3.63
236	1790	11.0	2.05	0.056	0.48	0.20	3.74
268	2420	14.0	1.61	0.089	0.36	0.26	3.62
253	2260	14.5	1.73	0.094	0.37	0.21	3.58
347	2100	12.0	2.09	0.070	0.64	0.22	3.60
163	2140	12.5	1.62	0.079	0.41	0.22	3.97
360	2000	13.0	2.10	0.065	0.65	0.22	3.56
252	2220	14.0	1.76	0.064	0.40	0.23	3.62
251	2320	15.0	1.68	0.061	0.41	0.23	3.57
351	2310	12.0	2.12	0.053	0.63	0.24	3.50
268	2420	14.0	1.61	0.089	0.36	0.26	3.62
320	2120	12.5	1.70	0.047	0.58	0.30	3.90
187	2220	14.0	1.54	0.072	0.43	0.35	3.78
160	2200	12.0	1.68	0.064	0.54	0.36	3.72
193	2290	13.5	2.09	0.101	0.51	0.46	3.53
155	2100	9.5	1.83	0.060	0.61	0.48	3.75
Avg.	2140	12.8	1.80	0.069	0.48	0.24	3.68

Table 18

LOW-PHOSPHORUS SERIES

Set No.	Ultimate Strength, lbs.	Drop Test.	Si	S	Mn	P	TC
18	2230	12.0	1.73	0.081	0.38	0.78	3.51
49	2270	13.0	1.92	0.051	0.42	0.78	3.63
161	2250	10.0	2.12	0.077	0.52	0.72	3.54
118	2050	10.0	1.94	0.066	0.60	0.80	3.65
58	2020	9.5	1.87	0.074	0.48	0.80	3.52
40	2160	12.5	2.01	0.061	0.56	0.80	3.69
117	2080	11.0	1.92	0.060	0.53	0.82	3.76
156	2370	10.5	1.70	0.070	0.57	0.89	3.63
41	2100	11.5	1.50	0.054	0.41	0.91	3.72
245	2060	11.0	1.85	0.075	0.46	0.95	3.48
Avg.	2160	11.1	1.86	0.067	0.49	0.82	3.61

increasing phosphorus in the cupola mix increase or decrease the transverse strength and resistance to shock?"

Data recorded in Mr. MacKenzie's paper* on the influence of phosphorus in cast iron indicated that phosphorus reduces transverse strength and resistance to shock when carbons are about the same. His paper on the influence of phosphorus on total carbon content showed that as phosphorus is increased, carbon is decreased; so that, when phosphorus is different, carbons are not the same. This, of course, leaves the foundryman in the dark and leaves unanswered much of the question as to the effect of phosphorus on the physical properties of cupola gray iron.

I have attempted to answer this question by the use of results in both of Mr. MacKenzie's aforementioned papers. However, in order to avoid as much as possible the doubtful results of obtaining transverse strength by calculating, I have picked out all of Mr. MacKenzie's tests within a fairly narrow range of silicon, sulphur and manganese, and have used only results of tests on bars made from blast-furnace pig iron. I have arranged these in Tables 17 and 18 in high-phosphorus and low-phosphorus series, the former including bars with phosphorus under 0.50 per cent and the latter with phosphorus from 0.50 to 1.00 per cent.

While the average transverse strength shows only a very slight increase due to phosphorus, it will be noted that 20 per cent of the tests in the low-phosphorus series showed transverse strength under 2000 lbs. Lest it be objected that the high-phosphorus series contains not enough tests to warrant definite conclusions, I would like to point out that a few years ago in the pipe plants of the Birmingham district no iron was melted which ran under 0.70 per cent phosphorus. Thousands of transverse tests were made, and practically all bars showed over 2000 lbs. transverse strength. No steel was used in the mixes from which these bars were melted.

* See footnote * on page 945.

It will be noted that the average carbon in the low-phosphorus bars is only 0.07 per cent higher than the average carbon in the high-phosphorus bars; Mr. MacKenzie's papers on the influence of phosphorus on total carbon content showed that the low-phosphorus bars should have been 0.14 per cent higher. This, of course, does not mean that one paper contradicts the other; it simply means that in securing data to find the influence of phosphorus on carbon, Mr. MacKenzie was more careful to make melting conditions the same for comparable tests.

However, if we want to know the exact influence of phosphorus on cupola-melted iron, we must first find the influence that 0.07 per cent carbon will have on the transverse strength and the drop test. With this in view, I have taken data from Mr. MacKenzie's paper on the influence of phosphorus on cast iron and have made two curves (for brevity, I have included only one of the curves, Fig. 16, in this written discussion). These curves indicate that 0.07 per cent carbon decrease will increase the transverse strength 140 lbs. and the results of the drop test 0.6. Thus, to find the strength of cupola low-phosphorus iron as compared with that of cupola high-phosphorus iron, we must deduct 140 lbs. from the transverse strength and 0.6 from the drop test of the low-phosphorus series, which makes the comparative transverse strength and drop tests as follows:

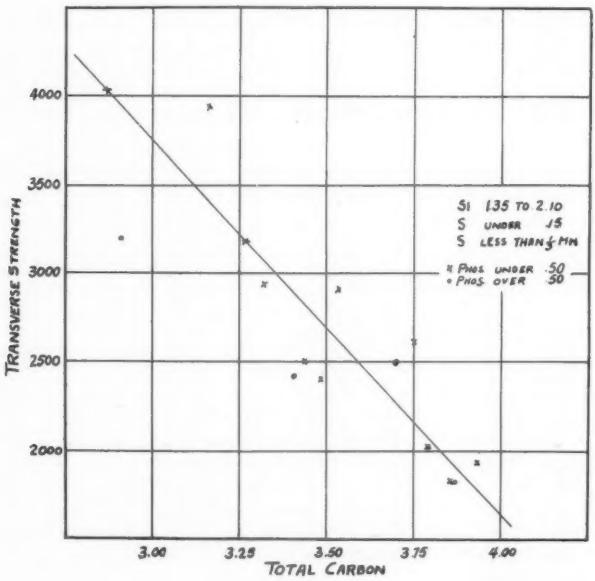

FIG. 16

Low phos. (0.24)—2000 lbs. trans.; 12.2 drop test
High phos. (0.82)—2160 lbs. trans.; 11.1 drop test

If the results of the tests of the two series had been "calculated to equal carbons," the results would agree quite closely with the results obtained by MacKenzie in his paper on the effect of phosphorus on cast iron.

Thus, we get a little better transverse strength and a little poorer drop test with an increase in phosphorus. The small increase in transverse strength perhaps evenly balances the decrease in the drop test; and, for all practical purposes, it might be said that phosphorus up to 1.00 per cent has no effect on the strength of cast iron.

W. W. KERLIN:[3] With regard to the deflections on the static transverse tests, how do they compare with the increase obtained in transverse strength?

H. R. CLARKE: I suppose there is some way to calculate changes in deflection due to changes in carbon brought about by increased or decreased phosphorus. However, I did not attempt to make these calculations. Of course, when carbon is decreased, the deflections are decreased when the load is the same in both cases. I believe that is generally known.

CHAIRMAN H. BORNSTEIN:[4] Mr. Kerlin's point was this: Mr. Clarke stated that, in the transverse test, the effect of increasing the phosphorus was to increase the load. What effect did it have on the deflection?

H. R. CLARKE: It decreased the deflection. I do not believe there is any question about that.

W. W. KERLIN: Was that probably the reason for the slight decrease in the dynamic test?

H. R. CLARKE: No doubt there was some relationship between the decrease in deflection and decrease in drop test.

J. T. MACKENZIE: One point I have observed in connection with deflection is that, when a great deal of brittle constituent is obtained, such as iron sulphide or the iron phosphide, it will be found that the deflection is increased in spite of the fact that the metal is white and apparently very stiff and brittle.

Using an iron of 0.8 per cent sulphur, we find that it bends very much more than it should for its silicon and carbon content. These brittle constituents seem to act like the graphite in the bending test, in that they crush and yield and give an abnormally high deflection.

As to the influence of the phosphorus on the deflection, we find that the influence is very small up to 0.30 per cent, but that it does stiffen considerably beyond that point.

Mr. Clarke's point—that, if a high-phosphorus pig iron is charged, a lower carbon material is obtained—is, I believe, well taken. The phos-

[3] Metallurgist, Gray Iron Institute, Cleveland.
[4] Metallurgist, Deere & Co., Moline, Ill.

phorus gives higher strength, not because it is present, but because the carbon is not. However, I believe that the general statement is perfectly correct, that phosphorus with the same carbon content does decrease the deflection.

MEMBER: Has Mr. MacKenzie found any effect of the wear due to high phosphorus, or probably the phosphides?

J. T. MACKENZIE: No, except that in certain types of wear, as with sugar-cane rolls, it has been found that with the high-phosphorus metal the little hard particles will stand out and grip the cane, and the wear in that case is very much better. Ordinarily, however, in wear resistance there is trouble from the weakness of the phosphide constituent itself as it breaks off and acts as an abrasive. Accordingly, if the wear is mild so that it will not tear out the phosphide, it increases the wear resistance; but if it is severe enough to break the particles out, it makes the wear resistance very poor.

N. A. MOORE:[5] I have often wondered just how far, in ordinary foundry practice, we can vary sulphur and phosphorus without noticing it in the casting. On the work that we are making, six or eight years ago it used to be common practice to have our sulphur down under 0.05 per cent and our phosphorus up to 0.5 per cent. Since that time, about three years ago, our sulphur ran up to 0.130 per cent and everyone expected that the shop would have to shut down. Apparently, however, there was no difference in the machinability or the quality of the product we were producing.

The same thing seems to be true of phosphorus, to a certain extent. We have run phosphorus from 0.2 to 0.5 per cent on some of our larger castings without being able to notice any difference in the tension of our piston rings, which is really a measure of the tensile strength, in a way, or the same sort of measure that tensile strength gives us.

Consequently, I am wondering on what class of work Mr. MacKenzie would figure that the phosphorus has the most effect, and what content he means when he talks about high phosphorus. Is that content over 0.5 per cent?

J. T. MACKENZIE: Mr. Clarke's division was 0.5 per cent, as I remember it. The irons running about 0.8 per cent are what we would call the high-phosphorus irons in the Birmingham district.

N. A. MOORE: Do you feel that under 0.8 per cent would be a high-phosphorus iron?

J. T. MACKENZIE: In France they speak of 1.90 as a high-phosphorus iron.

N. A. MOORE: That is another thing I have never been able to understand—how European practice and American practice can be so different in respect to phosphorus and still both apparently produce satisfactory castings.

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[5] Metallurgist, Piston Ring Co., Muskegon, Mich.

CHAIRMAN H. BORNSTEIN: I believe the answer to that is the availability of raw materials. One must get along with the raw materials available, and over on the other side they have high-phosphorus iron. They do not use high-phosphorus iron because they particularly desire it, but because they simply have to use it. They must govern their technique to take care of the available raw materials.

I believe that in the automotive field it is quite customary to have the phosphorus under 0.25 per cent. It is very interesting to get this expression from Mr. Moore in respect to the phosphorus varying from 0.2 to 0.5 per cent without having any effect on the casting. I would like to have someone from the automotive field tell us how they feel about increasing the phosphorus, say, up to 0.5 per cent.

ARNOLD LENZ:[6] We have found that in automobile practice in general there is a definite point at about 0.25 per cent phosphorus over which we cannot go and still get satisfactory castings. In our case we try to keep just as low as possible, perhaps at 0.16 or 0.18 per cent phosphorus. We had an experience not long ago when our stock of pig iron was not quite balanced, causing us to go up to 0.24 per cent phosphorus. After the metal was thoroughly saturated with that much, we ran into trouble.

As to machinability, we cannot find much difference until we get into the higher content of phosphorus, and then we have a very definite condition.

We used to run soft iron up to about 0.50 per cent phosphorus. If we ran above 0.50 per cent, say, up to 0.75 per cent, the metal in the soft iron became very crumbly, and the peculiar feature was that it took the edge off tools just like emery. Below that point it did not make so much difference.

Mr. Moore may not find the difference in his test because most of his work is ground.

Years ago the practice was to use high-phosphorus iron in soft metals. When production of automobile cylinders was first started, we naturally wanted to run high phosphorus, and it was quite a battle to give it up. Finally, however, we found that in order to get solid castings we had to reduce our phosphorus and raise our temperature. Now we melt at high temperature and get the phosphorus down as low as 0.16, 0.17, 0.18 and 0.19 per cent. In our plant we try not to run over 0.20 per cent.

In the soft castings we dragged behind, because they were not subjected to high pressures and it did not make so much difference; but we ran into adverse machining conditions. So long as they were running at 50, 60 and 70 feet a minute we were all right; but when they started to run at 90 feet a minute it was very different. Now they run up as high as 150 feet a minute, and at those speeds we can definitely tell that the high-phosphorus iron will not stand high-speed machining. It may be pretty soft and extremely soft in Brinell, but it is hard on the tools.

[6] Manager, Gray Iron Foundry, Chevrolet Motor Co., Saginaw, Mich.

R. S. MACPHERRAN:[7] Our experience was exactly like that of Mr. Lenz. Some years ago we changed what we called our high-phosphorus iron to a low-phosphorus one. The high phosphorus was about 0.60 per cent and the low about 0.25 per cent. We found that we could machine the identical casting satisfactorily with a very much lower silicon, if we simply kept the phosphorus down.

J. T. MACKENZIE: I would like to make oue more remark, that there are some cheap English cars like the Rolls-Royce that are made with 1.25 per cent phosphorus.

[7] Chief Chemist, Allis-Chalmers Mfg. Co., Milwaukee.

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